

THE THEORY *and* PRACTICE *of* ROLLING STEEL

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PREFACE

UNTIL the end of the nineteenth century, designing of rolls was attended by considerable mystery which seriously retarded advancement. Roll pass design was considered to be a secret art, carried out behind closed doors and passed along from one roll designer to another, as the alchemists of old carried out the art of making gold in their laboratories.

Few good books in the English language on the subject of roll pass design are to be found. Continental engineers have been more liberal with their experience and have published their knowledge for the benefit of others. The translation of Professor Tafel's book was undertaken in the hope that it would assist in filling in this gap in the English literature on the science of rolling.

The primary aim of the translator has been to present accurately the conceptions of Professor Tafel, whose extensive investigations have laid the foundation for many advances in roll pass design. The book is an explanation of the underlying phenomena and an attempt to find both a reason for and a solution of each of the problems which confronts the roll pass designer.

As Professor Tafel states, the book is an introduction into the theory and understanding of rolling and roll pass designs. His intention is not to show solutions of miscellaneous problems, but to help the reader to solve his own problems. It aims to give an insight into the reasoning which is necessary for successful roll pass design.

The author discusses nomenclature, calculation of spreading, forward slippage, gripping, and defects in the stock due to improper roll design. It deals with wear of rolls, overfilling and underfilling, location of the passes

in the roll, with side work and with many other features of roll pass design. The text deals with errors made in the design and with their consequences, and then enters into roll pass design for flats, skelp and hand and guide squares, in each case giving reasons for each step. Pass design for roughing rolls, roll train resistance, and pass design for structural material and similar shapes are treated in detail. One subject which seldom is discussed in books of this character, namely, the design of guides and guide boxes, is explained at some length.

The English edition is conceived in the spirit of the original volume, and, if there are shortcomings, they must be laid at the door of the translator. Great care was used in the translation of the material, but a few mistakes may have crept in. The translator will appreciate having them brought to his attention. He hopes, as does Professor Tafel, that this volume may stimulate wider interest in the numerous phases of roll design.

To the many friends and fellow workers in the steel industry who have aided him in the translation of this book the translator would express his sincere appreciation.

RICHARD RIMBACH.

Pittsburgh, February, 1927.

Preface To Second Edition

In his second book on rolling steel Professor Tafel has had an opportunity to revise the text of the first edition in the light of late developments in theory and practice. Changes appear throughout the book, especially in chapter VI, and considerable new material has been added.

R. R.

Pittsburgh, May, 1931

THE THEORY AND PRACTICE OF ROLLING STEEL

I

THEORIES AND RULES OF ROLLING

ROLLING can have for its purpose first, the compression of material to make it denser, that is, to do away with or to diminish blowholes, pipes and similar cavities, and to squeeze out inclusions of slag; second, to reduce the cross section of the material; or lastly, to change the shape of the cross section. The compacting and reducing of the cross section is called cogging or blooming, while the shaping is termed finish rolling.

Compression was important before the introduction of steel, because the puddle-balls of wrought iron were saturated with slag like a sponge with water. A portion of this slag was squeezed out, and the occluded particles in the form of fine threads distributed over the whole cross section of the iron. The more evenly and fine the distribution, the less slag pockets occurred and the better the material. This again was accomplished more thoroughly the larger the original cross section was when rolling started. That refined and double-refined iron, which is subjected to repeated heating and rolling, is better than iron heated once, rests principally on this fact.

Since steel predominates today, compressing is of

little importance. It lessens blowholes and also the pipe, sometimes in the same proportion as the cross section is reduced, but generally to a larger extent, because the displaced material first squeezes toward the cavities. On the other hand the tendency of the steel to pipe increases with the size of the ingot cross section. It is, therefore, more correct in the steel plant to strive for a dense structure by making an ingot of small cross section, than to use a large amount of energy to roll down a large ingot to make it dense. In other words, the ingot should not be chosen for size but for soundness of structure.

The second object to reduce section, is the purpose

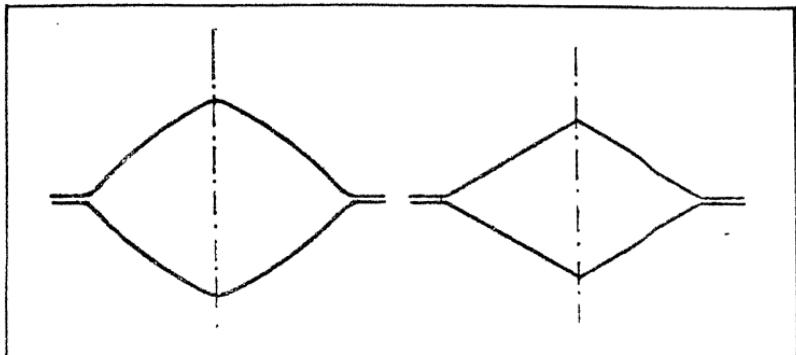


Fig. 1—Gothic and Diamond Forms of Roll Passes Frequently Used in Merchant Mill Practice

of every mill regardless of the material. Each mill produces profiles of different sizes of cross section. Due to this practice the ingot, from which rolling begins, also must have a different cross section. If the change of shape is begun immediately, that is, in the first pass, a different ingot or billet would have to be passed into the roll train each time. Naturally this would be inconvenient. It is preferable to choose either a single ingot cross section for all products of the roll train or at least for a large number of them and then to reduce these to the cross section necessary for the particular finished product on a blooming or cogging mill. Blooming also is nec-

essary for other purposes. A wire, which must be finished in long draws, would require such a long billet if it were not cogged that no furnace would be long enough to hold it.

The third object, the shaping, always is the most important, when the finished product has a different shape of cross section or a different profile than the ingot or billet which comes to the rolls. The cross section of the rolls is rectangular or square, although the gothic or the so-called diamond forms, shown in Fig. 1, sometimes are used. The last pass, in most cases, is rolled with less reduction of cross section than all the others. They are called polishing or finishing passes because they barely polish the surfaces: in most cases the contour of the

Fig. 2—Periodic Sections Used for the Manufacture of Rail Spikes and Horseshoes

hard rolls is formed by grinding with an emery wheel. Where two passes are used, the first is the preliminary polishing or finishing known as the leader pass and the second the final polishing or finishing.

If an ingot or billet of square cross section is put through the rolls, it is pressed into a rectangular shape. If steel rectangular in cross section is put through the rolls so that the axis of the cross section remains in the same position, that is, the horizontal remains horizontal, it is called a flat pass. If in the following pass the horizontal axis is placed vertical, it is called an edging pass.

To the types of profiles there still belongs the so-called periodic section, that is, on the circumference of the roll at different places there is a changing dissimilar

profile. Such, for example, are rolled for horseshoe or rail spike manufacture, as shown in Fig. 2, and for other forging purposes. The periodically occurring enlargements later are worked into the head of the spike or replace in advance the material which flows away on bending as, for example, in horseshoes.

If the cross section of the material to be rolled or a particular part thereof before the pass (passage through the rolls) be denoted by Q_1 , after the pass by Q_2 , then the diminution of cross section = $Q_1 - Q_2$. The relation of the two cross sections $\frac{Q_1}{Q_2} = a$ is called the reduction of co-efficient. The diminution of cross section generally is called reduction. In this treatise, however, the reduction, A , is not understood as the reduction of cross section in square inches, but the percentage in reference to the original cross section Q_1 . Therefore,

$$A = \frac{Q_1 - Q_2}{Q_1} \times 100.$$

Disregarding the spread, which in most cases is only a small percentage of the change in cross section, the reduction is determined by the increase in the height of the rolled material. Designating the height before rolling as h_1 , after rolling as h_2 , the reduction, disregarding the spread, can be expressed most accurately as

$$A = \frac{h_1 - h_2}{h_1} \times 100$$

For example, the reduction of a pass in which the height is reduced from 3.15 inches to 2.835 inches, considering the foregoing omission, is:

$$\frac{3.15 - 2.835}{3.15} \times 100 = 10 \text{ per cent}$$

By draft, also called absolute draft, ($h_1 - h_2$) is understood the difference of the heights before and after the pass.

While the draft of two profiles on the same rolls may remain constant, that is, remain independent of the

setting of the rolls in relation to one another, the reduction and relative draft will change if the setting is changed. In the foregoing illustration, if the distance between the rolls is increased 0.78-inch by raising the top roll, h_1 would be 3.93 inches instead of 3.15 inches and $h_2 = 3.615$ inches instead of 2.835 inches. Therefore, the draft would be $3.93 - 3.615$ or as before 0.315-inch. The reduction would no longer be 10 per cent,

$$\frac{0.315}{3.93} \times 100 = 8 \text{ per cent}$$

This plays an important part in the design of roll

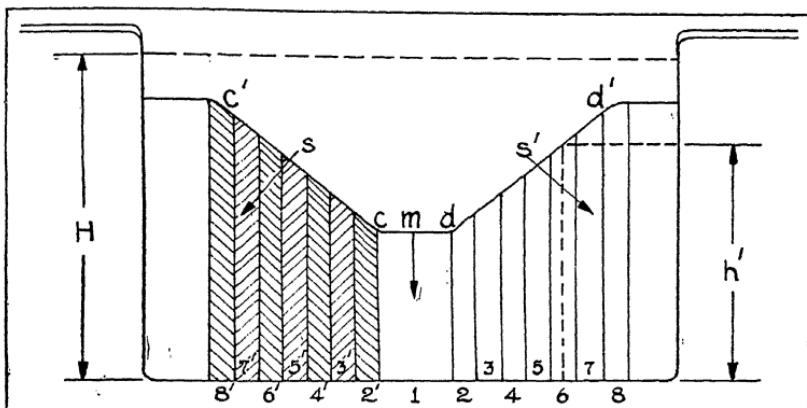


Fig. 3—Direct Draft or a Reduction of Height in the Vertical Direction Is Shown at M , S and S'

passes for flats and hoop iron as will be shown later. The elongation n is the reciprocal of $\frac{Q_1}{A}$, and therefore $= \frac{Q_2}{Q_1}$. If n is substituted in the foregoing equation for the per cent reduction A , then,

$$n = \frac{1}{1 - (A \div 100)} \text{ and } A = \left(1 - \frac{1}{n}\right) \times 100$$

Direct draft, called draft for short, is the difference in the height of the material before and after the pass, that is, a reduction of height in the vertical direction;

indirect draft is when the rolls exert a pressure on the material in a nonvertical direction. Accordingly at m in Fig. 3 there would be direct, at s and s' indirect draft. This distinction is somewhat doubtful.

If the parts of the cross section to either side of m are divided into a number of small rectangles, as roughly shown in Fig. 3, each small rectangle is under direct pressure, that is, the original height H is squeezed down

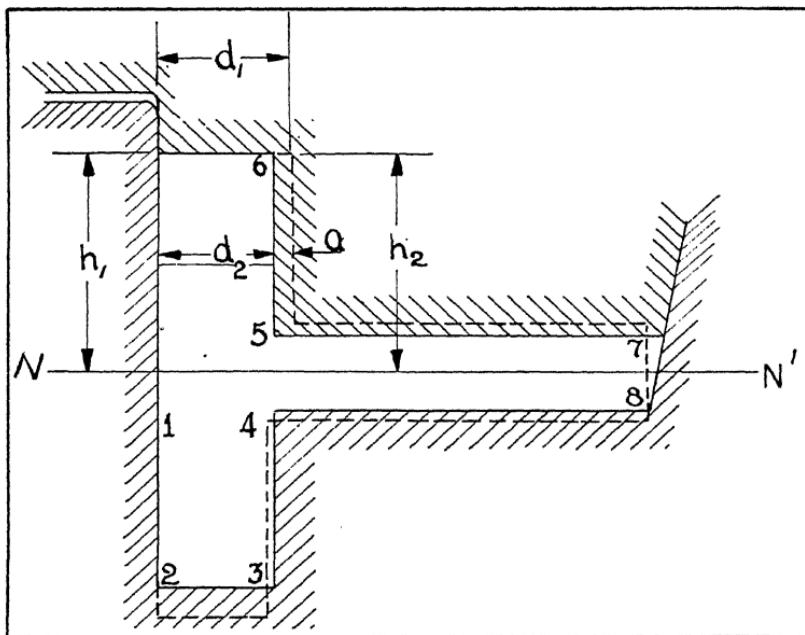


Fig. 4—Upper Half of Head Receives Indirect, Lower Half Direct Draft

in a vertical direction to the height of the section-lined rectangles, as for example to h .

It will be shown in a later discussion when irregular passes are considered, that the results of practical tests substantiate this explanation. This is no longer the case, if the roll surfaces cc' and dd' in Fig. 3 exerting the pressure are no longer at an angle to the roll line but per-

pendicular to it, as is the case in Fig. 4 with the surfaces 3, 4 and 5, 6. Under certain conditions there also can be a draft, that is, a reduction of section ($d_1 - d_2$), in a horizontal direction. This is shown by the section-lined outline in the upper half of the pass. These can no longer be resolved into a vertical pressure by cutting up the profile into small rectangles. Indirect draft throughout the text will be taken to mean such a horizontal dimension reduction.

The height, H , of a rectangle, A , in Fig. 5 can be

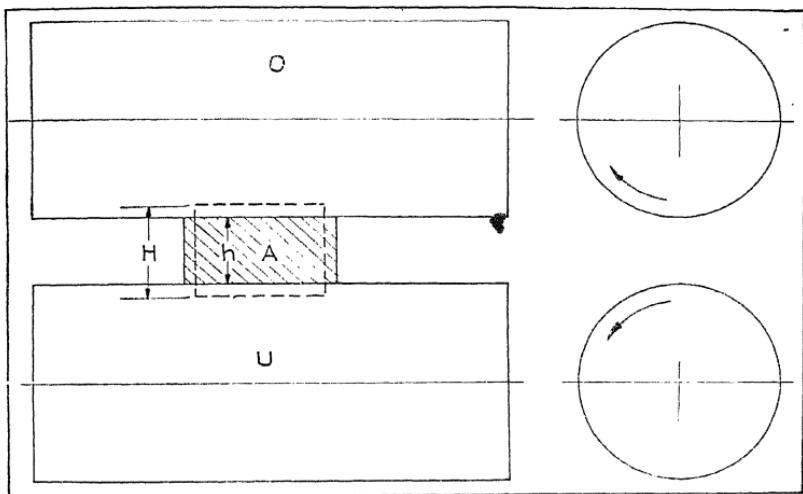


Fig. 5—Cylindrical Roll Surfaces Showing Direct Draft

worked down by rotating bodies to the height h , in either one of two ways:

1. By using the means already known, letting the piece pass between the cylindrical surfaces of two rolls turning in opposite directions;
2. By letting it be ground between two disk-shaped cylinders as L and R in Fig. 6 which work against one another like two millstones.

Seamless tube rolls depict these two conditions. In general the rolling mill operator makes use of only the form of rolling shown in Fig. 5. In this method of using a grooved pass, as can be seen from Fig. 4, the method of working shown in Fig. 6 will take place. As previ-

ously mentioned this in an indirect draft. From this consideration it follows that for roll pass design the use of indirect draft is only permissible in such parts of the pass as are bounded by different rolls. This is true in Fig. 4 only in the half of the pass which lies above the center line. When the particular part of the cross section lies in one roll such as the bottom roll in Fig. 4, direct draft only can be used.

The demand placed upon the roll surfaces 1, 2 and 3, 4 in Fig. 4 in working material, is similar to trying to grind grain between two mill stones running the same

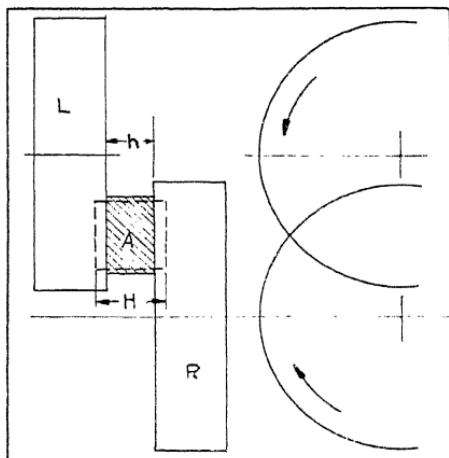


Fig. 6—Disk-Shaped Roll Surfaces Showing Indirect Draft

direction and at the same speed. While indirect draft is impossible in the lower part of the pass in Fig. 4, the reduction in height or direct draft is possible. The broken line shows the rolled material before the pass.

Between the indirect draft in Fig. 6 and at the top of Fig. 4 and the direct draft in Fig. 5 intermediate stages prevail. The indirect draft does not stop at any one certain slope any more than the direct. The usual view is that indirect draft occurs as soon as the pressing roll surface at the line 5, 7 in Fig. 4 is no longer parallel, but at an angle to the roll axis. This theory is as incor-

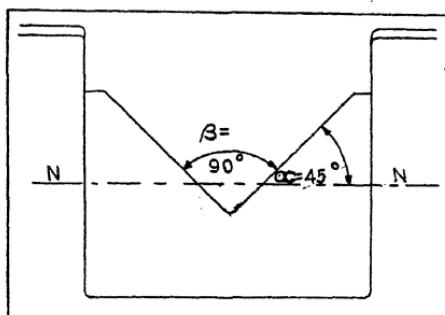


Fig. 7—Angle of Cutting-In Wedge

rect, as to assume that the draft is direct, as soon as the pressing surface at the line 5, 6 is no longer perpendicular, but at a steep angle to the axis of the roll. Also, in the last case the effect of the rolls is more of a grinding than of a pressing down character; but in addition to the first the latter begins. How these effects gradually change from one to the other, is not definitely known. The author has determined by tests, that the rules for direct draft appear to hold fairly well, where the slope of the pressing surface makes an angle of $\alpha = 60$ degrees, with the roll axis as shown in Fig. 7, $\beta = 60$ degrees (angle of cutting-in wedge). The rules hold for $\alpha = 45$ degrees, $\beta = 90$ degrees.

From about $\alpha = 60$ degrees down, the effect of the indirect draft compared with the direct draft, appears to get stronger. Accordingly, the transition of the one

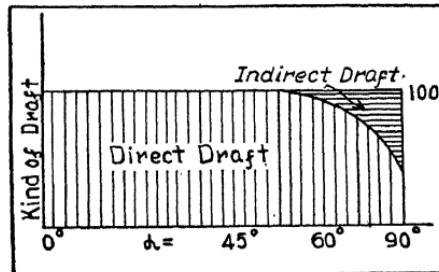


Fig. 8—Limits of Direct Draft

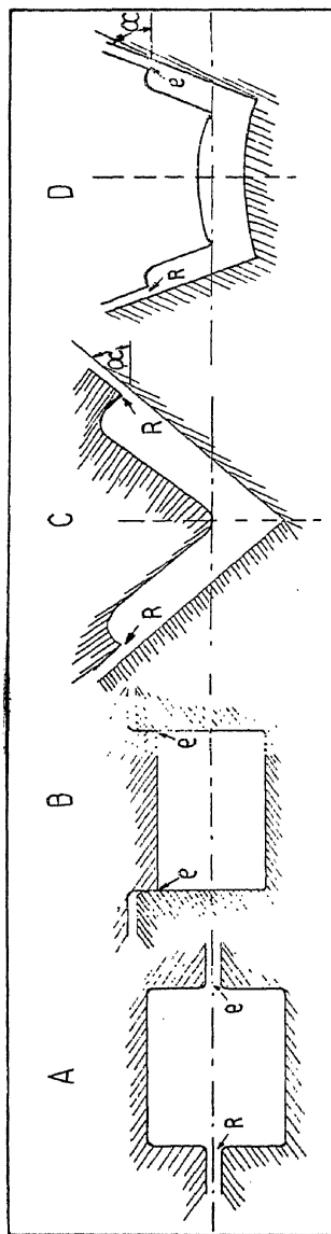


Fig. 9—Various Types of Open and Closed Passes

to the other can be assumed to follow the course shown in Fig. 8. From the parallel position $\alpha = 0$ degrees, the material movement depends entirely on the direct draft, with 90 degrees all on indirect; between 45 and 90 degrees it is partly due to the former and partly to the latter.

A section at right angles to the direction of rolling, that is, to the axis of the rolled rod is called the profile. If the profile is enlarged according to the expansion which it undergoes on heating to the rolling temperature, it is called the hot profile. If the rolls are grooved, the surface in the plane of the rolls, which the rolls release, is called pass. If the pass is bounded partly by the lower roll and partly by the upper roll, the place at which the boundary changes from one roll to the other is called the parting of the pass. If the parting is formed by lines, which are parallel to the roll axis, it is called an open pass as in Fig. 9A, and if they are perpendicular, it is a closed pass as in Fig. 9B.

The designation for intermediate position varies. We will consider it an open pass, if the angle between the roll-axis and the pass boundary at the opening (α) is smaller than 60 degrees as in Fig. 9C; a closed pass, if it is 60 degrees or larger as in Fig. 9D.

α never is exactly 90 degrees because the rolls usually are grooved conically to facilitate the delivery of the rolled material and also, to bring a used pass back to the original shape when dressing. The conical surface, the arc of the angle $R - \alpha$ in Fig. 9, is called taper. It amounts to at least 1½ per cent in all passes; in rectangular sections it is never over 15 per cent. On the other hand in shape passes the taper upward is unlimited.

The rolls turn on their necks. As the compressed material exerts a counter-pressure against them, they must be prevented from moving apart. This is accomplished by using bearing bronzes, which can be replaced in the bearings, called chocks and which, by means of the adjusting screw or wedge, hold the upper chock

down, and the lower one up. These parts press together when the stock passes through the rolls; the space between the necks and the bearing bronze, the bronze and the chock, and, between the latter and the adjusting mechanism is diminished. The parts are pressed tighter against one another. This makes for a certain spreading of the rolls which is unavoidable at the instant the stock is gripped. This is called the springing or the spring of the roll. It varies according to the diameter of the roll and the draft to which the stock is subjected and can be taken to vary from 0.039-inch to 0.787-inch; or from 0.5 to 0.8 per cent of the diameter with rod mill rolls and from 0.8 to 1.5 per cent with cogging or structural mill rolls.

Many roll designs do not consider the change of form in rolling bodily, but as taking place in a plane.

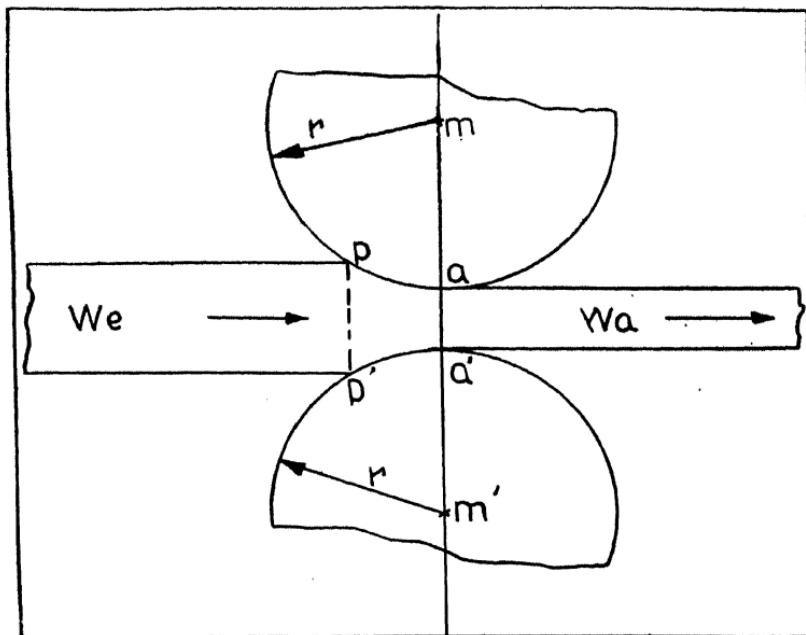


Fig. 10—Reduction of Cross Section of Rolled Material Starts When the Rolls Grip the Piece

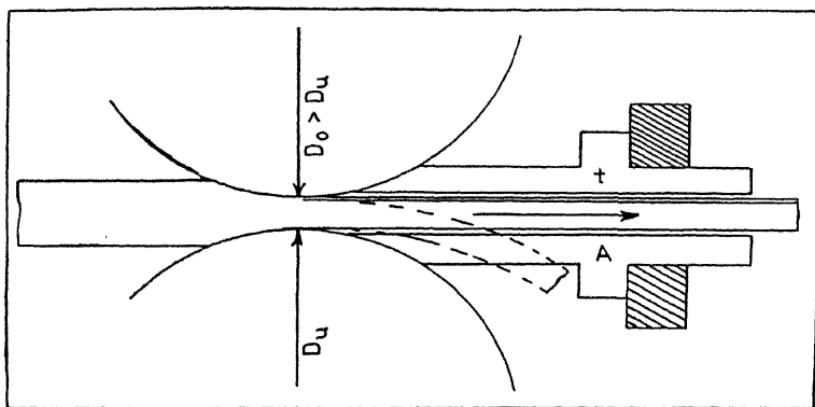


Fig. 11—Type of Stripper Guide Used to Afford a Perpendicular Deliverance of the Piece from the Rolls

The reduction of cross section of the stock begins, as soon as it is gripped by the rolls as shown in pp' in Fig. 10. It stops the instant the plane is reached which can be imagined as containing the axis mm' of the two rolls. This is called the plane of the rolls and is shown in the section $mam'a'$. Entrance and exit of the stock takes place in a direction perpendicular to the plane of the rolls. This direction is called the rolling direction. To assure such a perpendicular direction, guides, known as receiving, delivering and stripping guides, are used. These are shown in Fig. 11. The delivery guides in the form of loop troughs often extend from the rolls in an arc, but the stock for a short distance at least should leave the rolls in a direction perpendicular to the plane of the rolls and tangent to the surface of the rolls.

The diameter measured in the pass as for example Da_3 , Da_2 , Da_3' and Da_2' in Fig. 12, which is called the working diameter, ordinarily is not the same size in the upper and lower rolls. If it is larger in the upper roll, the pass has overdraft; if the opposite is the case, it has underdraft. The measure of both as already has been shown, is the difference between the working diameters. Pass I in Fig. 12, therefore, has 24.016 inches — 23.622 inches = 0.394-inch overdraft.

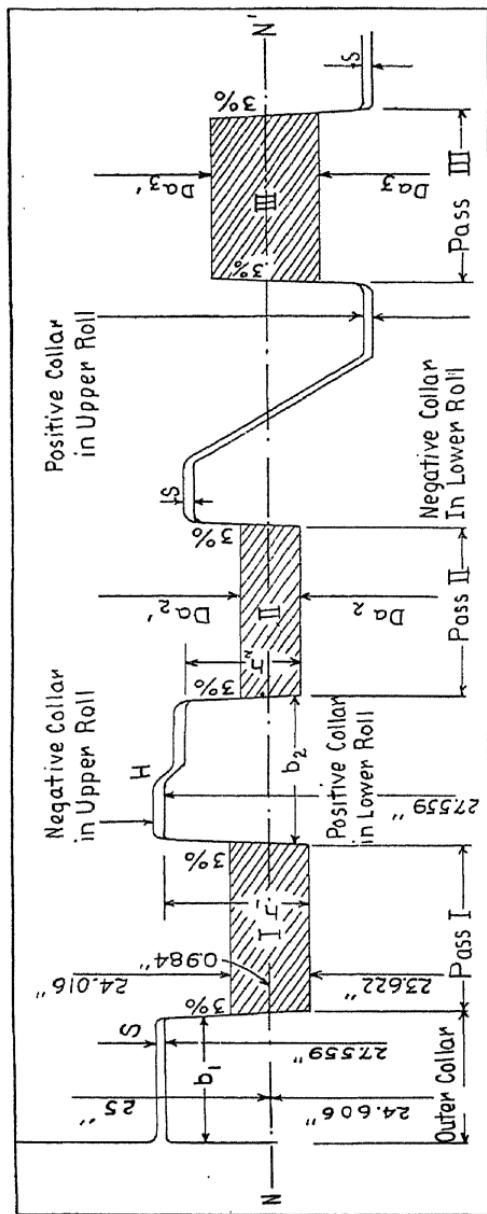


Fig. 12—Section of a Roll Drawing. At the Right Is Shown a Change from a Positive to a Negative Collar

The object is that if the working diameters are the same size the material, pressed against the roll surfaces, sometimes would stick to the top and sometimes to the bottom roll, according to the roughness of the particular spot. It is, therefore, necessary to make provision above and below, so that the piece will leave the rolls perpendicular to the plane of the rolls, that is, the piece does not lift or go down around the roll and form a ring. A stripper guide is used above and below indicated by *A* in Fig. 11. It is possible to get along with only one, if for example the upper working diameter is made 0.2-inch or 0.4-inch larger than the lower. Due to the higher circumference speed of the upper side of the pass the fibers of the rolled material in contact with the roll there will accelerate; the piece, therefore, will have the tendency to bend down, pressing on the bottom guide. In this event the upper guide will be unnecessary. When the rolled material is in contact with the sides of the grooved pass, it exerts a pressure on them and is easily wedged into the roll, which has a tendency to pull it along. If this roll were given an overdraft, the material would tend to lift itself. Both effects would counteract each other. As a rule the overdraft or underdraft is not given to the grooved or female roll but to the so-called male roll. The two effects then will add up and it can be determined to which side the piece has a tendency to go around the roll. The stripper guide in most cases is set on the lower roll.

Same Size of Overdraft Used

As a rule the overdraft for all passes of a roll is made the same size. Many rolls are made with an overdraft of 0.4-inch. This amount is found with many structural and rod mill rolls in Germany, while with blooming mill rolls the overdraft ranges from 0.79-inch to 1.18 inches.

The larger the overdraft, the more the action of the rolling process becomes one of grinding; the smaller it is the more it becomes a pressing process. It is assumed, as in the first case the internal change of shape

is greater, that a large overdraft makes possible a greater changing of shape but gives a lower efficiency and higher stresses. Scientific investigations as yet have not been made, so the values of the overdraft previously mentioned and which were found by experience are used.

The decrease in height, for example, of a rectangular cross section, $d = h_1 - h_2$, is not divided equally between the two sides of the center line of the pass, but as far as is known, is smaller on the side of the larger roll and larger on the side of the smaller roll.

II

TECHNICAL CONCEPTIONS OF ROLLING

MANY of the considerations found in literature on the rolling process, constitute a colored mixture of ideas and theories. Some ascribe the appearances in rolling to different cooling, through which the single layers of the rolled material pass, according as they are nearer the outside and, therefore, in contact with the cold surface of the roll, or toward the center and, therefore, at a distance from the surface; others

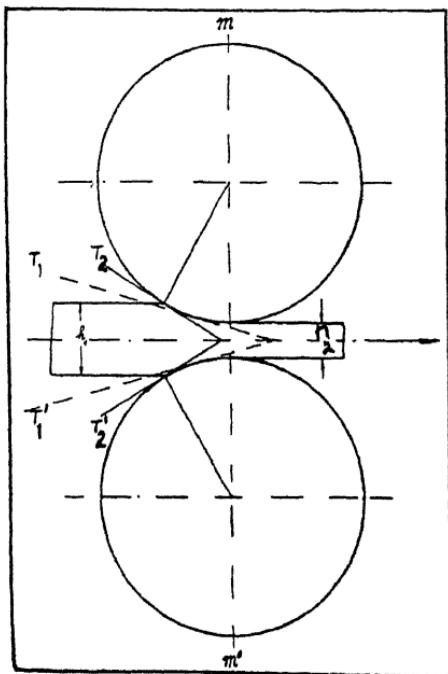


Fig. 13—Diagram of Tangential Forces

emphasize positive tangential forces such as T_1 and T_1' in Fig. 13, if the tangents intersect in front of the plane of rolls MM' , and of negative T_2 and T_2' if they intersect behind.

The positive forces draw the material into the rolls, the negative forces press down. The effect of friction between the roll and the material, and the theory of flow is not readily understood. Some consider rolling a pressing process; others a drawing process. In the first case we think of the rolls as two semicircular dies indicated

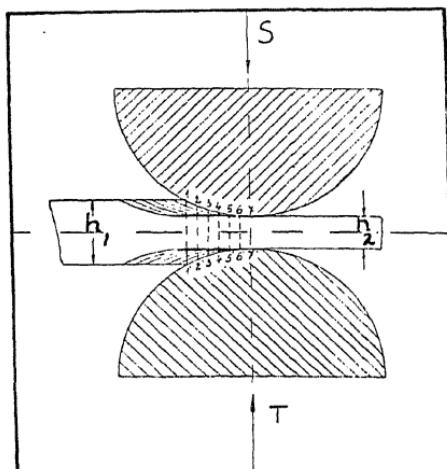


Fig. 14—Rolling Process as a Pressing Procedure

by S and T in Fig. 14, which move up and down and between which the material is pushed slowly at intervals from the rear. Another view is that the process essentially is a drawing of the material between the rolls, considering the single planes $1 1'$, $2 2'$, etc. up to $7 7'$ in Fig. 14 as a hole gradually getting smaller, through which the material is pulled as through a drawing die.

Brovot, in his book entitled *Design of Rolls*, compares the action of rolling with the rolling of dough using a rolling pin and with the rolling of ground with steam roller. These undoubtedly are the nearest to

the rolling process, if we consider the movements relatively, that is, the rolled material as being still and the plane of the rolls moving over it. Only in the case of the steam roller the ground to be leveled is a material of infinite thickness to be rolled. The rolling pin has in the board under the dough a fixed surface, while in the same case of the rolling process the thickness of the material is finite and in place of the fixed surface, there is a second lower roll which turns with the same or almost the same speed. Fink had pointed out the fundamental difference from the drawing process, stating the parts of the surface of the rolls, which work similar to the drawing die and reduce the cross section, are not stationary as is the case with the walls of the drawing die, but move in relation to the plane of the rolls in such a way that they pull in the material. Fink in his article on the "Theory of the Rolling Work" in 1874, made detailed calculations of the work of the rolls in the process according to Fig. 14 (pressing the height h_1 to the height h_2) and he determined that $A = V \times k \times \ln n$, in which V is the volume in cubic inches, k the elastic limit in compression at the temperature under consideration and n the elongation. He then investigated mathematically what friction is necessary between the rolls and the material in order that the latter will be drawn into the former against the resistance which the great thickness exerts against the passing through. He arrives at the same expression, if it is assumed that for the whole distance 1' 1" to 7' 7" in Fig. 14 the rolls and material have the same speed.

Slip Must Occur Between Points

Fink determined this assumption was not correct, but that between the points mentioned, that is, between entrance and exit, a slip must take place between the rolls and the material. He calculated the additional frictional work, which resulted from the inequality of speeds, as 13 to 31 per cent of the actual work of deformation according to the size of the angle of grip and the

height of the material. Fink in addition derives mathematically, that this additional frictional work, as well as the portion of bearing friction must be proportionately larger, the smaller the reduction; a fact, Kiesselsbach also determined practically by the Puppe investigations. The processes of rolling and that of drawing and pressing differ widely.

In drawing, a round rod first is pointed out and then threaded through the hole in the die, which is smaller in diameter than the rod. The end, as shown in Fig. 15, is grasped by tongs and the rod is pulled in the direction shown by the arrow. As the rod has a larger diameter to the left of the die than the opening, the walls of the die press on the rod and attempt to press it

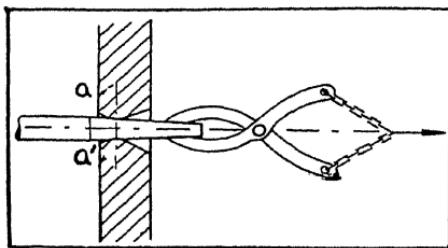


Fig. 15—Position of Dies for Drawing Round Bars

together. Metal will permit little compression especially if it is wholly dense. As the tongs continue to move, the section to the right of aa' will be lengthened and experiences a contraction, as is the case with a rod pulled in a tensile machine. At the same time material is drawn from the rod to the left of aa' . In this way it is contracted and can give way to the pressure of the die and slip a distance through the latter. The procedure continues for the whole length of the rod. That the process is one of contraction, rather than one of compression follows from the fact that wire after drawing generally shows a lower specific gravity than before. Seldom, and then only in the first drawings does it increase a small amount.

In rolling, as far as can be determined, loosening never has been determined. The characteristics in rolling are totally different. The material is not as before drawn out of the core of the rod, but the place aa' in Fig. 15 and $7\ 7'$ in Fig. 14 is pressed down, from the cross

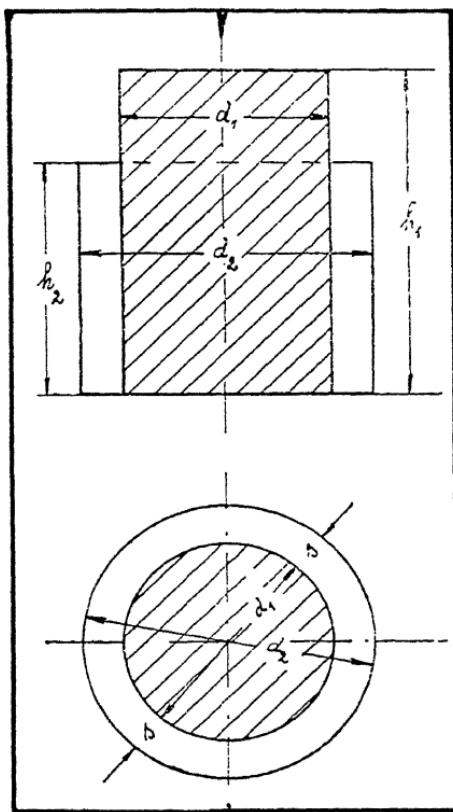


Fig. 16—Average Path Covered by Material During the Pressing Process

section lying to the left, to a larger extent than the cross section $7\ 7'$ gives it out as will be discussed later.

Fundamental differences exist between the pressing process and the rolling process. If a cylinder of red hot

steel is placed under a steam hammer or a forging press and reduced from the height h_1 in Fig. 16, a cylinder of large diameter d_2 results. In this as in every intermediate step if the unimportant compression work on the material is disregarded, the following must hold:

$$h_1 \times \frac{\pi d_1^2}{4} = h_2 \times \frac{\pi d_2^2}{4} = h_3 \times \frac{\pi d_3^2}{4} = \dots = h \times \frac{\pi d^2}{4}$$

As the volumes remain equal, the cross section must increase in the same proportion as the height decreases. Plotting the heights on the X-axis of a co-ordinate system and the cross sections on the Y-axis gives the curve,

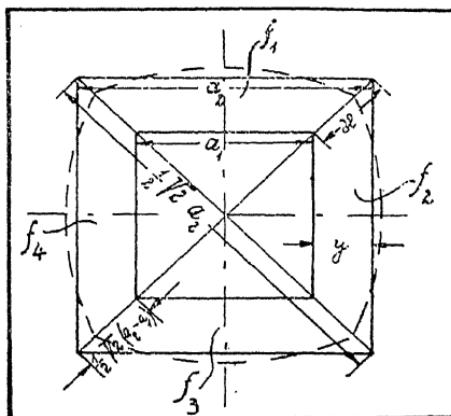


Fig. 17—Pressing a Square Cross Section

$daX \times y = \text{constant}$, a hyperbola. The same holds for the pressure curve because the prevailing pressure at any time is equal to $(3.1416d^2 \div 4) \times k$ if k denotes the compressive elastic limit of the materials, and is proportional to the cross section at the particular position.

The particles of the material as shown in Fig. 16 cover an average path to the side equal to $S \div 2$. The larger the path, the more will be the deformation work. This path is smallest when the circular shape is retained. With a uniform material, temperature and vertical pressure a cylinder pressed down must again give a cylin-

drical form. If a square prism is pressed its form is not retained. If this form were retained, as shown in Fig. 17, the average path of the particles in the corners would be larger than the path in the center of the sides of the square.

$$\frac{1}{2} \sqrt{2} (a_2 - a_1) \text{ exceeds } \frac{1}{2} (a_2 - a_1).$$

Here also the smallest amount of work is performed. The least resistance is when an equal average path is covered by the particles. The square sides will bend out to the shape shown by the broken lines in Fig. 17. The same amount of material moves out on each side of the square, $f_1 = f_2 = f_3 = f_4$. Rectangular shapes

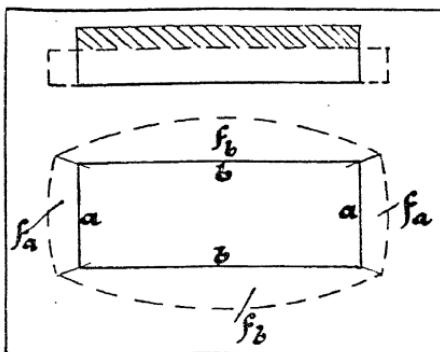


Fig. 18—Diagram Showing the Unequal Displacement of Material

also are subject to change as shown in Fig. 18. With the rectangle $a \times b$, more displaced material will move out on the side b than on the smaller side a . Therefore, f_b is larger than f_a ; the total path covered by the displaced particles is smaller, than would be the case if f_a was the same size as f_b . Therefore, the length of the sides open for the displacement of the material influences considerably the direction in which the displaced material of a compressed body flows.

If the rolls in Fig. 14 are replaced by two dies going up and down, a rectangle is pressed down. One side is the width of the rod to be rolled and the other is the

horizontal projection of the part of the roll circumference which touches the material as depicted in Fig. 16 by arc 1 , 7 and $1'$, $7'$ respectively. The more material, therefore, that is squeezed out on the side in the direction of spread, the greater it is in relation to the other side of the rectangle, or the width, of the rod to be rolled. All other conditions being equal, a rod spreads more, the larger the roll diameter. A larger roll diameter also means a larger contact surface between roll and material, as shown in Fig. 19.

The imaginary pressing procedure previously designated as rolling, is not covered by the regular pressing

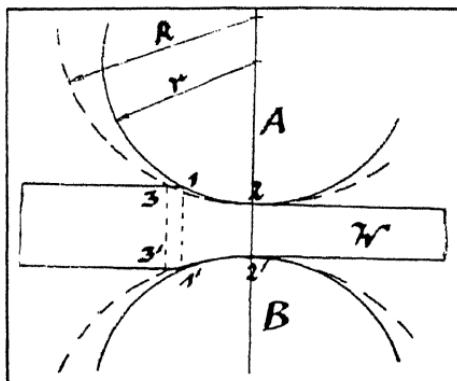


Fig. 19—Spread with Different Roll Diameters

because the diminution of height is the same all over, while in the case of the rolling procedure it increases from the one to the other narrow side. As previously mentioned the pressing plates are stationary, while the roll surfaces move toward the one narrow side of the rectangle. The rolls attempt to carry along in the same direction by friction the particles of the material with which they are in contact. The particles displaced in height are not permitted to flow equally to all sides as is the case with the pressing process, but the direction of movement of the rubbing rolls will be predominating for the flowing off of these particles. We will call it the

“assigned direction.” It not only plays an important part in rolling but also in deep drawing of plates, in drop-forging and in other manufacturing process.

Will material move without slip between the points 1' and 7' in Fig. 14 which represent the entrance and

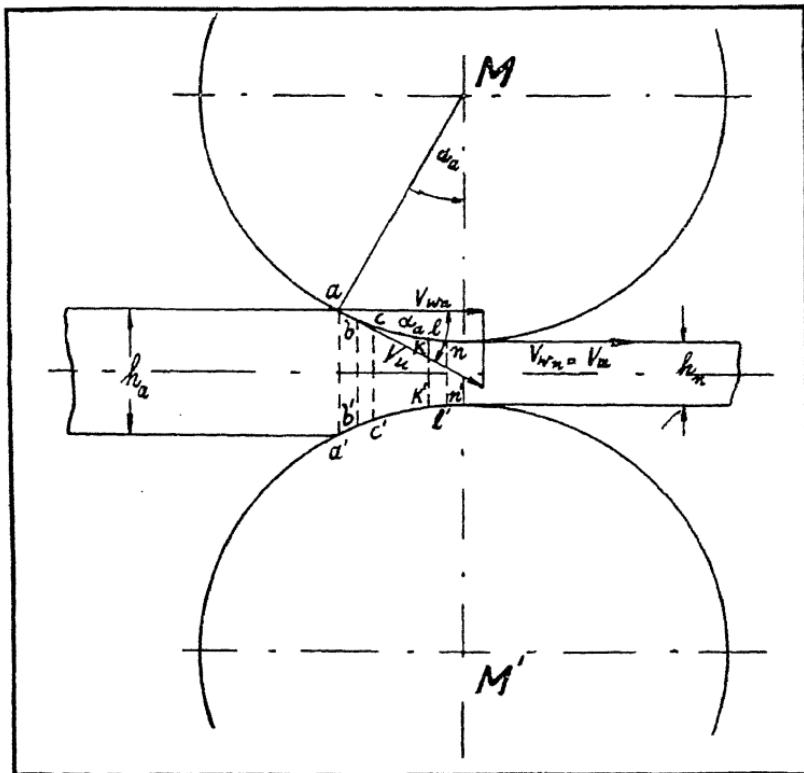


Fig. 20—Relation of Rolling Speed to the Circumference Speed

exit from the rolls? In other words is the speed with which a point on the surface of the roll nears the rolling plane equal to the corresponding contact point of the rolled material?

The circumference speed of the rolls is constant and equals V_u as shown in Fig. 20. If the particles of the

material to be rolled, which are pulled along by the roll surface, move themselves forward without slip, then the horizontal speed, with which the particles a near the roll plane MM' in the point, is $a = V_{wa}$. This is designated as the rolling speed. It is $V_{wa} = V_u \cos a$ in which a is the

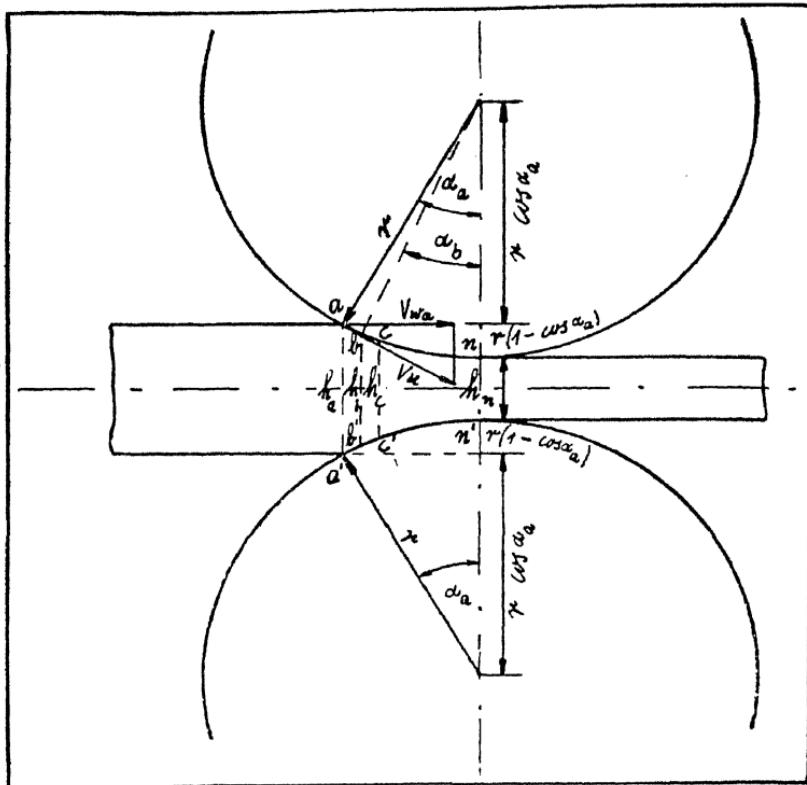


Fig. 21—Diagram Showing the Volume Passing Through the Rolls

angle at any position, which V_w and V_u make with one another. The line connecting the entrance point a with the center of the roll forms the same angle a with the roll plane, MM' called the angle of grip; because the radius r is perpendicular to V_u and V_{wa} is perpendicular to MM' , angles with sides respectively perpendicular are

equal. $\cos a$ is smaller than 1 between $a = 0$ and $a = 90^\circ$. With $a = 0$ it is equal to 1; therefore at that place the roll speed equals the circumference speed, always assuming no slippage. Then from n toward a , that is, from the exit toward the entrance, the angle a increases, the $\cos a$ and with that V_{wa} ($= V_u \cos a$) also gradually gets smaller.

An unconstrained passage of material through the rolls without slip can obviously only take place, if in the unit time the same volume of material as leaves the rolls would pass the point a and also at the intermediate points b, c , etc. That is, if B equals the width of the material to be rolled then, $B \times h_a \times V_{wa} = B \times h_b \times V_{wb} = B \times h_c \times V_{wc} = \dots = B \times h_n \times V_{wn}$ (1). The equations show that passage without slip is only possible, if the heights from n toward a (h_n, h_1, h_c , etc. to h_a) increase in the same relation, as $V_w = V_u \cos a$ decreases. This condition can be proven mathematically but is not fulfilled by the circular cross section. If the dimensions are chosen this condition can be satisfied for 2 points but never for 3 or more. The condition is more readily understood when studied graphically rather than mathematically.

The increase of h from n toward c Fig. 21 can be expressed by the angle a and the roll radius r .

$$h_a = h_n + 2r(1 - \cos a_a) \quad (2)$$

$$h_b = h_n + 2r(1 - \cos a_b) \quad (3)$$

Equal volumes would pass through and no slip exists if from equation (1)

$$\begin{aligned} h_a \times V_u \times \cos a_a &= h_b \times V_u \times \cos a_b \\ &= h_c \times V_u \times \cos a_c \\ &= h_n \times V_u \times \cos a_n \end{aligned}$$

The expressions of Nos. 2 and 3 etc. substituted for h_a, h_b , etc., give $h_n \times \cos a_a + 2r(1 - \cos a_a) \times \cos a_a = h_n \times \cos a_b + 2r(1 - \cos a_b) \times \cos a_b = h_n \times \cos a_c + 2r(1 - \cos a_c) \times \cos a_c = h_n \times \cos a_n + 2r(1 - \cos a_n) \times \cos a_n$.

Each of these equations set equal to one another denotes the volume, which would pass the points a, b, c ,

etc. up to n , if the rolls could transport without slip. This volume is plotted in Fig. 22 as ordinates; the curve $r \cos a$ (for $a = 0$ degrees, 30 degrees, 60 degrees and 90 degrees) in Fig. 22A first having been plotted from any table of circular functions. The ordinates lying between it and the horizontal ss' determined by s , are then equal to $2r - 2r \cos a$ or $2r(1 - \cos a)$. These values, then

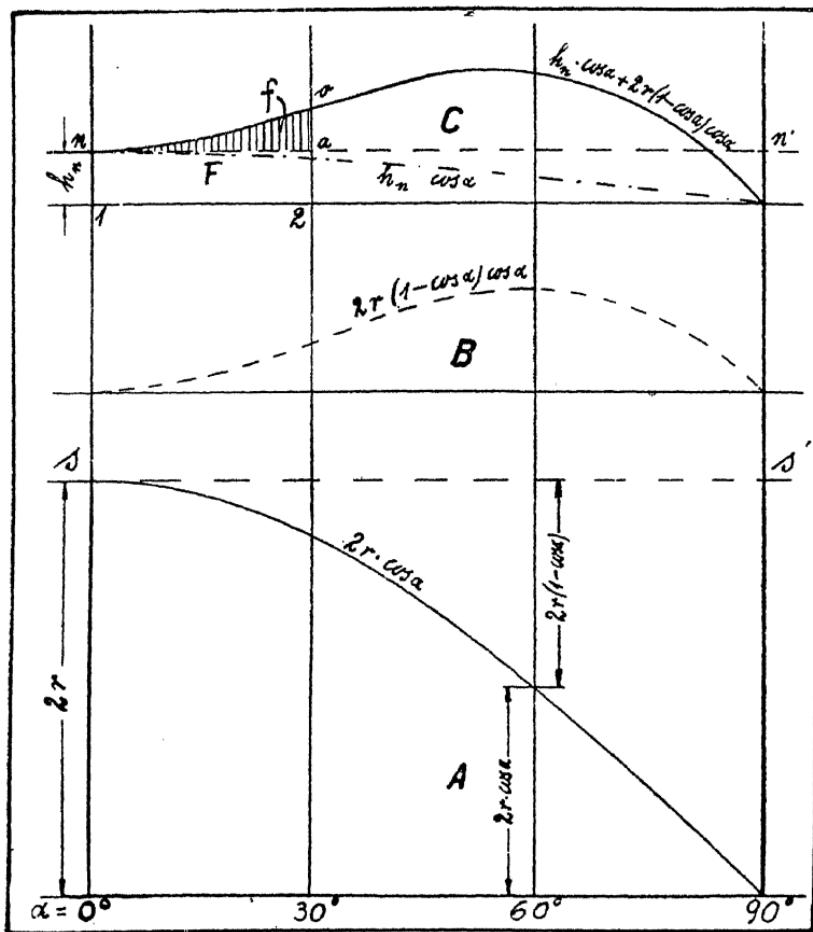


Fig. 22—Curves Which Denote the Volume Passing Certain Points if the Rolls Could Transport Without Slip

are multiplied by $\cos \alpha$, giving the broken line curve of Fig. 22B.

Finally Fig. 22C gives the curve for the expression $h_n \cos \alpha + 2r (1 - \cos \alpha) \cos \alpha$, called the volume curve, which was found by adding to the curve A for $h_n \cos \alpha$, the curve B.

It is simpler to determine the value passing through at each point per second. This volume is equal to the rolling speed times the cross section at the particular point. The rolling speed is equal to the circumference speed times the cosine of the angle of grip α , therefore, the volume passing each point $V = h B V_u \cos \alpha$. Since B and V_u are constant, the volume therefore is proportional to $h \times \cos \alpha$. If h at any point is expressed as h_n , then (see Fig. 21) $h = h_n + 2r (1 - \cos \alpha)$, and the volume at every point is proportional $[h_n + 2r (1 - \cos \alpha)] \cos \alpha$ = the ordinate in Fig. 22C.

This more complicated form for the volume passing through at each point has been retained here, because it denotes the relation to the roll diameter $2r$, which is of interest. For example, from Fig. 22, can be seen that with increasing roll diameter the volume curve is steeper. This is of importance for the standpoint of spread. A simple calculation shows that the volume rises above the horizontal from the beginning, as long as $h_n < 0.86$, which in practice is always the case. This means in all practical cases the rolls have a tendency (aa' in Fig. 21 and o_2 in Fig. 22) to draw in more material than they would deliver, if the stock and the roll surface have the same speed. A difference between entering and exit volumes naturally is not possible; moreover, in the same time the same amount of material must pass through the rolls at all points. Therefore, between the rolls there always is present a kind of drawing, upsetting effect in the horizontal direction. In other words, between entrance and exit the previous material always will press on the material closer to the rolling plane and attempt to push it ahead faster than corresponds

to the rolling speed. The equalization of the difference in volume, which endeavors to pass each point through the rolls, is only possible, because the material is practically incompressible:

1. In that, the material in the first part of the passage enters the rolls with less speed than corresponds to the circumference speed (Slip backwards).

2. In that, the material pushed forward from behind near the exit, goes through the rolls faster, than the circumference speed stipulates. (Slip forward, speed gain).

3. In that, the material, which is pushed forward faster from the rear, than the rolls are able to take up in the latter part of the passage, gives way to width (Spread). The accompanying equation No. 1 as will be recalled assumes the same width B of material during the whole passage. If at a Fig. 22C a volume enters the rolls equally to o_2 , while at n only one equals n_1 is let out, this inequality easily can be corrected in that the width at passing through the rolls increases according to the relation $o_2 = n_1$.

The balance is not effected by the spread alone, but probably according to the three reasons. In several cases a slip occurs according to the first reason. This can be seen plainly in the roll train, if a piece has so much draft that the rolls grip with difficulty. It also can be seen at the entrance of the steel that the rolls slide on the stock.

A similar result was calculated by Fink. He assumed that the slip between entrance and exit took place in such a way that the roll speed was not equal to the circumference speed at either the former or the latter, but at a point lying between the two, perhaps at l relatively l' in Fig. 20. He recognizes only the first and second possibilities mentioned previously.

If the three methods of balancing are expressed in

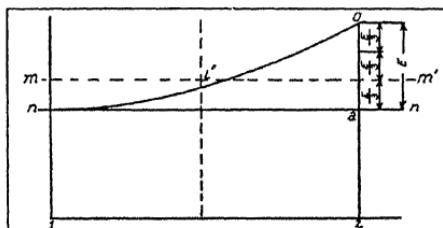


Fig. 23—Balancing of the Compression Force by Slip and Speed

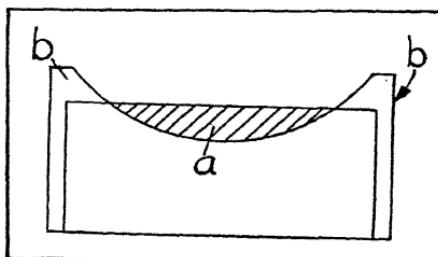


Fig. 24—Diagram of Material Displacement

the volume curve in Fig. 22, assuming that the compacting is divided equally among all three, then Fig. 23 can be derived.

The balancing, due to the difference of α_2 in comparison with α_2 , equals E . Of this approximately one-third goes to spread and a third each to slip retardation and speed gain. Designating the circumference speed of the rolls v_u , the actual rolling speed would not correspond with the conditional circumference speed at n , but at a point lying between α and n , which is designated as l as before. The width B would increase in the same relation as the exit speed. Finally the last third of E will go on the backward slip. Because it has not been possible to calculate the relation according to which the balancing is divided, the determination of the spread remains complicated. According to the foregoing relation $B_2 = B_1 \times (ml \div nl)$, the spread $B_2 - B_1$ must be proportion to B_1 , the original width of the stock. Therefore, a rod twice as wide would have to spread twice as much as one of unit width, all other conditions being the same. On the contrary, the linear spread decreases gradually with broad stock while narrow rods develop considerable spread. With the ordinary rod dimensions, the spread practically is independent of the width of the stock. This is shown in Geuze's formula, which is used mostly in practice for the determination of spread:

$$b \text{ (Spread of steel)} = 0.35d \text{ (Draft)}$$

That is to say, a steel rod lessened in height by 0.236-

inch will increase 0.079-inch in width following rolling.

An attempt was made to learn why the materials going into width in relation to its original width does not increase but rather decreases. The influence of adjacent parts of a plastic body first must be studied thoroughly. This fact is fundamental not only for

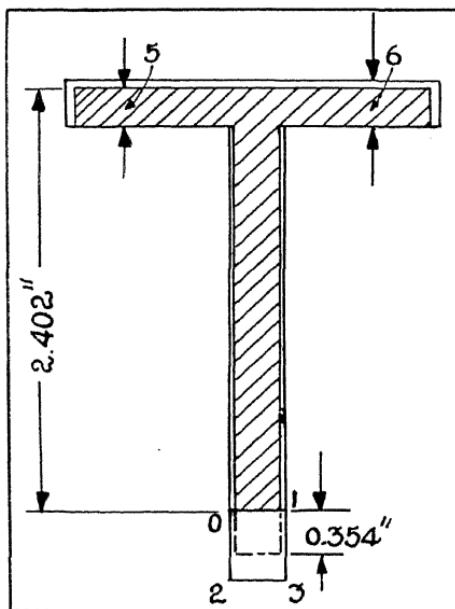


Fig. 25—Finishing Pass of a Tee Without Compression

spreading but for all rolling and other processes which change the form of hard and plastic bodies. Only with the recognition of this influence can roll design, forging, pressing and other processes in which bodies are heated and cooled, be understood. Experiments, which led to the foregoing recognition, and the mathematical determination of the size of this questionable influence will be discussed in Chapter V under the design of irregular passes. At this point only fundamentals will be discussed. Previously the roll designer considered that the

rolling process and the change of form in the rolls took place principally in the plane of the roll, that is, in the plane of the drawing. Fig. 24 shows that the displacement of the material from the hatched area *a* to the parts *b* not hatched, was only the flowing of the smallest particles in the roll plane. The central particles in this plane were pressed down and moved to the side or upward. That a part was elongation and stretched is conceded but the process is not considered important for roll design. For example the last pass of a tee usually is an edging pass as shown in Fig. 25. The head is given

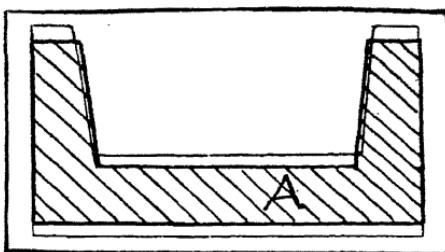


Fig. 26—Shrinkage of Outside Parts of a Channel Section

about 0.39-inch draft and in this case is equal to about 15 per cent; the web is upset about 0.354-inch. The web was permitted to go through the rolls without any draft to make the groove 0-1, 3-2 in Fig. 25 deeper. The question was, how high should the leader pass be, to have the finished profile come out hot with the height of 2.402 inches? Early contentions were that with 0.039-inch being taken off the head, this material would be squeezed into the web at the top as the web did not touch the roll at the bottom. In other words, the web would have to be 0.039-inch lower in the leader pass or 2.362 inches to have a hot finished profile of 2.402 inches. The draft on the head, was not increased but decreased, which means it shrunk. What was the cause?

The head had a draft of 15 per cent and as the spread was small, it was lengthened about the same

amount. The web, which received no draft, has itself nothing to make it elongate, but as it is attached to the head it is drawn along with it. The result is, that like a rubber band when drawn out it becomes smaller, which in this case was a loss in height. The nonfilling of the pass, or exceptionally large or small spreading can easily be explained if this mutual influence of the different

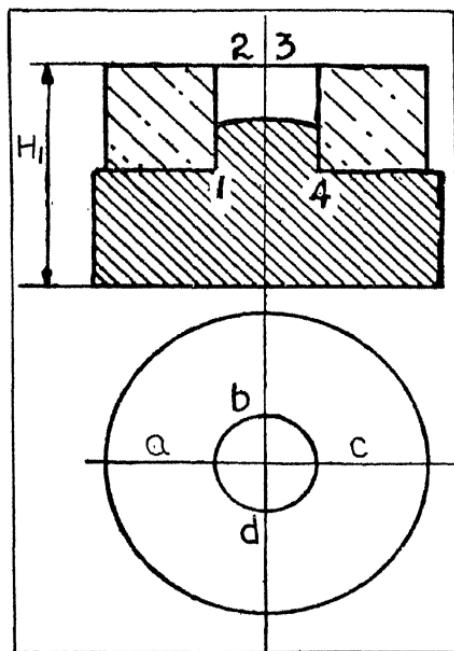


Fig. 27—Incomplete Filling When Pressing

pressed parts of the cross section is taken into consideration.

If, for example, a channel section, as shown in Fig. 26, receives more draft in the center than at the outside, the central part has a greater tendency to elongate, and therefore will pull along the flanges. The latter will retard the center. This is only possible if the displaced material flows from the part with the

larger draft to that with less draft in the same proportion. The nature of roll design lies in the recognition of this change effect between the shrinkage of the parts pulled along and the flowing away of material from parts of the cross section which are retarded. The flanges, drawn along, will not fill the pass if there is not enough of the pressed material to flow into them. The amount of the missing material can be determined as will be shown later, in presenting an answer to the question: What average length L_m will a rod take whose single cross-sectional parts take the lengths, L_1 , L_2 , L_3 , etc., if they were independent of one another?

When considering problems of rolling and pressing,

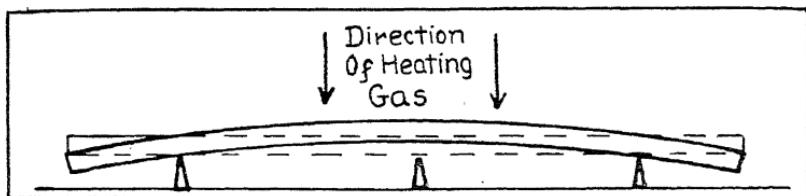


Fig. 28—Curling Action of an Annealed Shaft Exposed to Hot Gases in a Rod

the occurrences when castings cool, or, warpage resulting from hardening or tempering, the influence of adjacent parts which expand or contract unequally when not associated with one another is important. With a pressed body of the height H_1 , in Fig. 27, the outer parts are compressed. The material then would fill the cross section 1, 2, 3, 4 if no resistance were offered to the displacement of the particles, in other words if it were fluid. The larger the resistance, the less the material will climb into the hollow pass. In reality there is no prevention for climbing but the part pressed down pulls down the nonpressed middle part, the two parts being connected in the bearing surfaces. This is shown in the elevation by 1, 2, 3, and 4 and in the ground planes

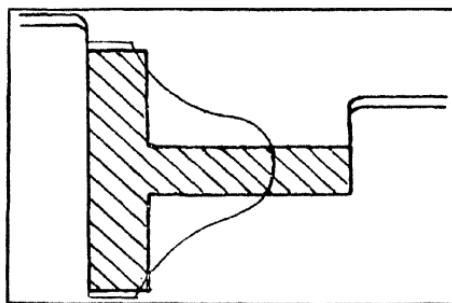


Fig. 29—Spreading Action in Rolling a Tee

a, b, c, and d. Furthermore, in the heat treatment of shafts, it frequently happens that they are bent slightly, particularly when the heating does not proceed uniformly on all sides from the beginning. After cooling off to the room temperature all parts are again at the same temperature, so they must have the same length at the end. The parts, which first bend, must straighten out again provided that in the whole period of heating and cooling the influence of the neighboring parts is the same. This is not the case.

The procedure in a cylindrical body, divided into two equal parts by a plane through the axis, of which one

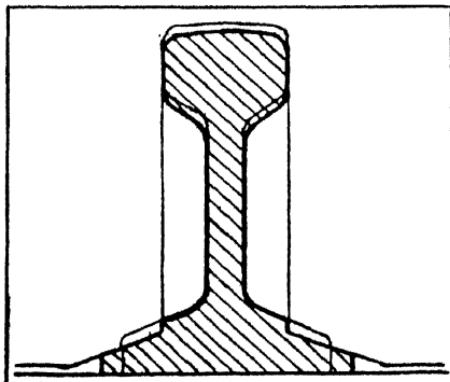


Fig. 30—Spreading Action in the Foot of a Rail

side gets heat and the other little or no heat, is as follows. The former, which is designated as the lengthening half, attempts to pull along the latter or the still half. The supposition is that:

1. The still half is plastic and offers no resistance to the flow. It will assume the same length which the one that is heated higher assumes due to the rise in temperature.

2. The still half resists being carried along by the other half. In this case the latter will be retarded or upset as it were, on the other side and the resistance will be converted in part into deformation work in the direction of bending. This is shown in Fig. 29. The material will curve with the side on which it rests toward the center of a curve.

A shaft for example, which is heated by the hot gases from the roof of an annealing furnace, assumes at first a higher temperature on top than on bottom and

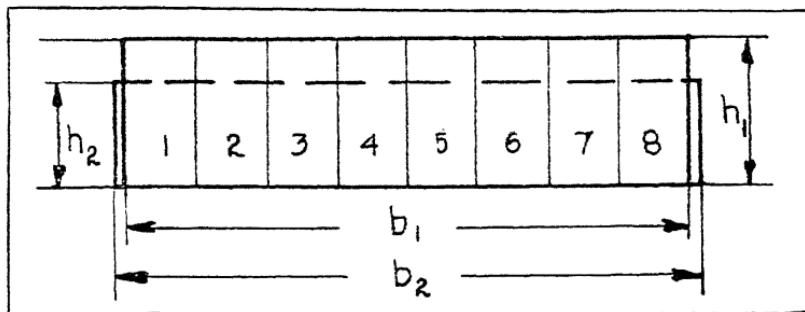


Fig. 31—Individual Parts of a Pass Taking Part in the Spreading Action

a curling in the direction shown by Fig. 28 occurs. The upper half reaches the temperature of the hot gases, about 800 degrees Cent. and is more plastic. The latter side of the cylinder takes on this temperature slowly. In this period the lengthening lower half will pull along the plastic upper half, lengthening it. A bending back will not take place and some of the first warping will remain after cooling, even though all cross-sectional parts again possess the same temperature.

A material, subjected to a heavy draft, but which is held back by the neighboring parts, will have the tendency to let the superfluous material go into breadth rather than length. Giving the head of a tee less draft

in the second pass, as shown in Fig. 29, is good practice in the development of the web to the breadth. The material in these passes as a rule still is hot and plastic. The head given less draft than the web will undergo less shrinkage. Moreover, some of the material of the web will flow into the head, another part will go into breadth. Such profiles, therefore, show an abnormally large spread.

A similar condition exists in the edging profile of a rail pass design. Due to the low resistance of the web

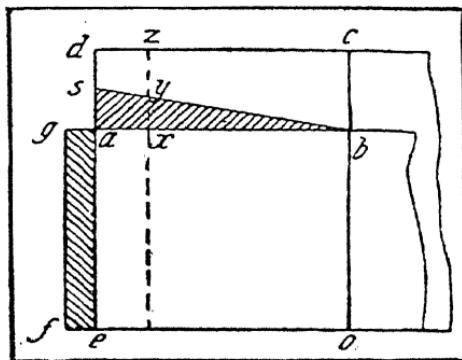


Fig. 32—Spreading Action of Outside Section

to buckling, the diminishing in height of the whole profile, shown in Fig. 30, only can be about 10 per cent. If it is made about 30 per cent larger on the outer flange parts, which still are in contact with the roll, the material from these cross sections is forced to spread rather than lengthen. The abnormal spreading provides a means by which to attain development of the flange. Conclusions derived from the foregoing considerations have led to a hypothesis in regard to the spreading procedure.

If the rectangular cross section b_1h_1 in Fig. 29 is divided into a number of equal parts, in this case eight, the first conclusion based on the fact that the spread is not proportional to the total width is that the single

cross sections do not take equal part in the spreading. If this were the case, a rod which had only half as many lamellae, could only spread half as much as that of the width b_1 . In considering how the parts 1 to 8 differ we notice, that the inner sections 2 to 7 have adjacent parts on either side and the outer or edge parts 1 and 8 only on one side. Assuming part 3 receives no draft it would be drawn along by its neighboring cross sections 2 and 4 like a rubber band, increasing in length and decreasing in height and thickness. The draft $h_1 - h_2$, which part 3 actually receives, is close to that received by drawing down and, therefore, will not meet any resistance in the longitudinal direction. In other words, as part 3 tends toward length under the influence of its neighboring parts, it will send the whole displaced material in this direction and will not spread.

Edge Pieces Present Different Condition

A different condition maintains with the edge pieces 1 and 8. These are connected on the inner side with a neighboring part while on the outer side they are free. With the former, as with the other parts, all the displaced material will go into length; the latter either will go into spread, or, a part into length and a part into spread. In Fig. 32 part 1, *eocd* is shown enlarged and assumed that the material acts as though forged but not influenced by adjacent parts, that is, equal parts go into spread and length. The whole of this displaced material is represented by the rectangle *abcd*. Let the ordinate, *xy*, represent the part of the material in every single longitudinal section which goes into width and *yz* that which goes into length. The curve, *bs*, which is received must pass through the middle of *ad* at the point *S*, if it is assumed that half of the material goes into length, and half into width. From recent investigations it appears probable, that the edge parts go entirely into spread, where no material is in the way. The height of the hatched triangle then would not be equal to half, but to the whole draft *ad*. On the

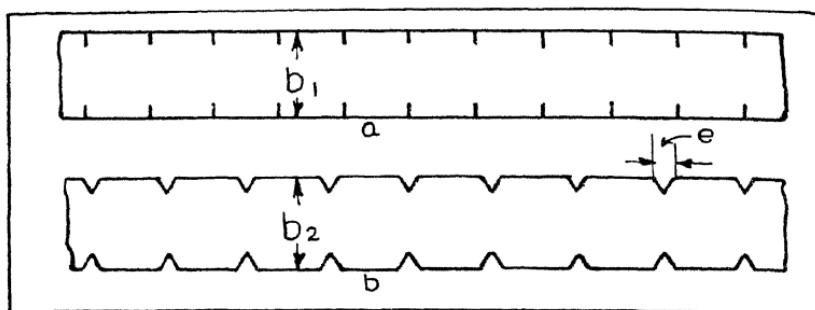


Fig. 33—Results of a Test for Spread on a Rod Slit Before Rolling

other hand the base of the triangle ab should be chosen only half as large, so that its area is equal to that of the rectangle $aefg$ going into spread. The further from the edge, the smaller the ordinate xy will be, that is, the more material will go into length, until finally at some point, b , the point is reached at which the influence of the edge, that is the spread, ceases.

The distance ab is called the influence depth. The curve bs is assumed as a straight line for simplicity. The triangle abs , called the intensity triangle, therefore, represents the stock that goes into spread; the trapezoid $bcds$, the material of the end piece; and $eocd$ going into length. According to hypothesis no part of the inner cross section goes into spread, and as the conditions at the right edge are the same as at the left, the material $feag$ going into width on each side must have the same area as the intensity triangle and the total spread must equal twice its area. If the latter is known,

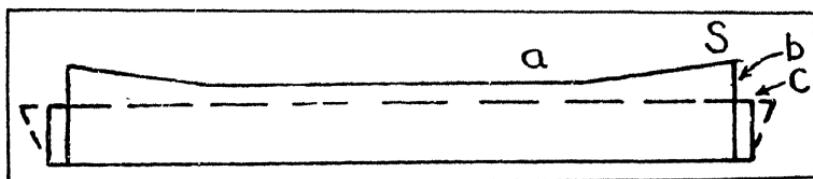


Fig. 34—Intensity Triangle in a Rod, Such as abs , Are Rolled Into Steel, Leaving the Corners Sharp and Angular

the depth of influence ab for the particular case can be calculated. If the depth of influence could be determined with a definite quality of material and temperature and a definite roll diameter, the spread could be calculated in advance.

That the foregoing hypothesis is correct at least quantitatively appears probable from experiments made by the author. For example:

1. A rod Fig. 33a was nicked on two edges with a cold saw and then passed through the rolls. The draft was 50 per cent. The nicks opened forming triangular notches as shown in Fig. 33b. This proves that less material goes into length at the outside than at the inside, and of the latter the amount drawn along increases the nearer it lies to the edge. The gapping notches are vertical intensity triangles transferred into the horizontal plane.

2. If in the interior of a rod all the material goes into length and the outer part into width, the surface layers must have a tendency to remain behind the inside. But due to the two being connected, the former are drawn along by the latter. In opposition to this they offer resistance in the form of stresses, which, as far as they lie below the elastic limit remain in the material after rolling, if they do not equalize themselves by cracking of the edges, as we observe in example 1 and also quite often with thin, cracked, so-called saw blade strip steel.

In a second experiment the author attempted to prevent the stresses by placing on each edge of a rod an area equivalent to the material going into width and equaling the intensity triangle abs in Fig. 34. The rod then was given a roughing pass and a pass through a pair of flat rolls. The result was that these intensity triangles were rolled wholly into the rod, without swelling out at c to the form shown by the broken line, or to leave a mark at a , as would be expected. The corners were sharp and angular as if machined. The rod no longer was straight as with a rectangular roughing pass but left the rolls bent like a flaming sword. The edges, which otherwise stress the interior of a thin rod and leave the rolls straight in spite of the unavoidable small unevenness of the roll surfaces, were without stress.

Recent investigations of W. Tafel and G. Pajunk have shown that the edges of a rod have a tendency to spread different than in its center. According to these investigations the mean spread is uniform over the

whole cross section; but in the individual horizontal planes there is a different relation between the edge and the center according to the kind of stress triangle. The following should always be kept apart in such observations: *First*, the spreads and elongations, which the individual parts would assume, if they were independent of one another. According to the Pajunk tests, their relation corresponds to the stress triangles. *Second*, the spreads and elongations, which they actually assume. That the latter as a mean, spreads uniformly over the width of a rod, is simply the result of the fact that as the parts are connected they must assume the same elongation.

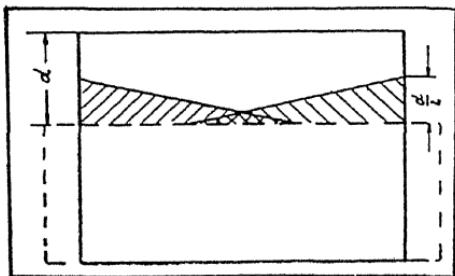


Fig. 35—Overlapping of the Stress Triangles

By the foregoing hypothesis, the appearance, of a narrow cross section of flat or hoop steel 0.394 to 0.472-inch wide which suddenly shows a large spread, can be explained. The depth of influence according to the hypothesis is independent of the width. If the latter is smaller than twice the influence depth, then the points of the intensity triangle cover one another, as shown in Fig. 35, and press each other to the side. The material going into width, therefore, increases and can amount to 50 per cent, if it is assumed that half of the edge part goes into elongation and half into spread and amounts to 100 per cent if it all goes into spread.

All the occurrences expressed in the foregoing experiments and theories, which have a certain relation,

unquestionably contribute to several remarkable phenomena of the spread. Summarized, the theories are:

1. The spread does not increase in proportion to the width of the stock, but practically is independent of it. Only with narrow stock such as flats and hoop steel does a sudden increase in spread occur at the expense of the elongation. Only with wide stock rolled in a universal mill does it approach zero.
2. The spread increases with increasing draft.
3. The spread increases with increasing roll diameter. Large roll diameters cause considerable spread and little elongation and vice versa.
4. The spread of a single part of a cross section can be lessened or wholly prevented, if pulled along by its adjacent parts it can be increased and the elongation wholly prevented, if it is held back by the adjacent parts.
5. Finally the spread increases with decreased rolling speed all other conditions remaining the same, especially the same roll diameter. Recent tests conducted by the author and Fr. Anke with cross sections 1.1 x 1.1 inches and smaller failed to disclose that the rolling speed influenced the spread appreciably.

An accurate mathematical determination of spread has heretofore not been successful in spite of the many attempts made in this direction. Spread usually is understood to be the difference of the width before and after the pass, as assumed in the previous section. Often it is taken as the amount a pass is larger than the previous one. Both ideas do not always mean the same. For the sake of distinction the latter will be designated by pass spread and the former by spread. The simplest determination is that of Geuze, who assumes that the spread is a function of the draft. His formulas are:

$$\begin{array}{ll} \text{Wrought iron} & b = 0.48 d \\ \text{Steel} & b = 0.35 d \\ d, \text{ the draft} & = h_1 - h_2 \\ & b = \text{the spread} \end{array}$$

These formulas give values which are too high for material ordinarily rolled, that is, steels of market quality. In this case, as in all others in the text, unless otherwise noted, commercial steel of a tensile strength from 54,000 to 57,000 pounds per square inch, is meant. Other material under the same conditions spreads less the harder it is although a larger spread may occur if the harder material is rolled colder. This generally is the case because with high-carbon steel there is more

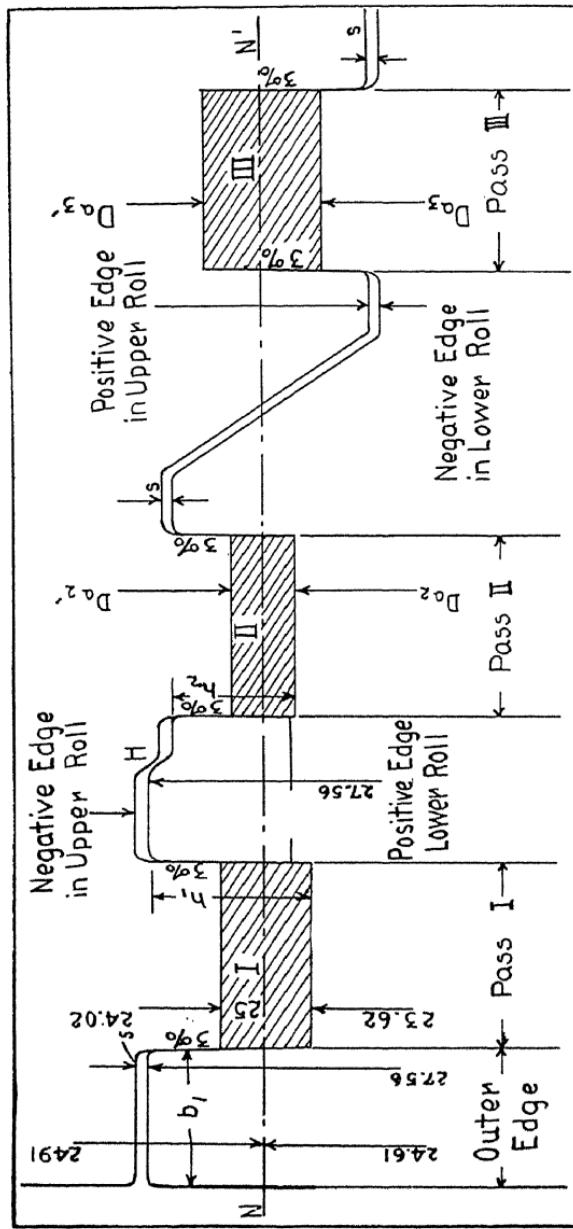


Fig. 36—Part of a Roll Drawing Through the Plane of the Rolls

danger of burning the steel when heating than is the case with soft steel. For the foregoing formulas the following substitutes are approximate. At temperatures of 1832 degrees Fahr. and higher, $b = 0.25 d$; for temperatures lower than 1832 degrees Fahr., $b = 0.33 d$.

The best check for rod mills so far obtained according to the investigations of W. Tafel and Fr. Anke is a formula of Siebel

$$\text{Spread} = B = c \sqrt{\frac{(h_1 - h_2)^3 r}{h_1^2}}$$

in which the constants c at the usual rolling temperature for copper = $\frac{1}{2.77}$, aluminum = $\frac{1}{2.22}$ and soft iron

$= \frac{1}{3.2}$ were determined.

Simpler, but giving larger deviations from the actual, is a formula of H. Sedlaczek,*

$$B = \frac{h_1 - h_2}{6} \sqrt{\frac{r}{h_1}}$$

Common to both formulas, even though they were derived in a wholly different manner, is the relation of the spread to the square root of the roll radius or the roll diameter. This is why they are presented here even though they do not contain all the factors, which determine the spread (width of the stock in front of the pass, temperature, rolling speed, etc.) and, therefore, do not hold in every case.

Roll Collars Defined

A roll drawing represents a section through the plane of the rolls and shows (see Fig. 36) the passes and the spaces between them which are known as the roll collars. If the roll collar is higher than the upper boundary line of the pass, it is called positive, if lower negative. Collars of the latter type generally lie in the upper roll while those of the positive type lie in the lower roll or vice versa. Frequently the positive and

*Stahl und Eisen (1925) page 190.

negative collars, as shown at the right of Fig. 36, change in the same roll.

The two collars between the outermost passes and the ends of the roll are called the outer, the others the inner collars. The number of the latter is with n passes on the roll, $n - 1$, the number of all collars is $n + 1$. The width of the roll collars, b_1 , b_2 , etc., depends on their height, h_1 , h_2 , etc.; the larger the height the larger will be the lever arm which the side forces, caused by the pressure of the rolled material, will exert on the collars. An old rule of thumb method is, that in the inner collars, b should be made equal to h , as shown in Fig. 36. This can be considered as the largest necessary dimension for cast rolls. Where no considerable side thrust occurs, the width can be made considerably less to save space. The same is true for rolls of forged steel, in which the collars are made half the height. Where a large indirect draft occurs, approximately with steel rolls the first rule must be observed. The outer collars generally are made somewhat broader than the inner collars, so that a guide or guide box at the edge of the roll will not interfere with the stands.

Rolls with positive collars are called grooved rolls while those with the negative collars are called tongued rolls. It is customary for the draftsman to show the rolls not with the circumference touching, but with a distance apart equal to the spring as shown in Fig. 36. Where different thicknesses are rolled with the same rolls, the roll drawing is based on the smallest thickness. The size of the spring s therefore, must be estimated. In hot rolling with small roll diameters of about 7.874 inches the spring is about 0.059-inch and increases with increasing diameter to about 0.787-inch.

As far as possible all dimensions in the roll drawing are expressed by the diameters, because the roll turner works only with the calipers. For example, in Fig. 36 the dimensions for h_1 or 1.969 inches is not given, but the height of collar is expressed by giving

the diameter of the roll at the bottom of the pass which is 23.62 inches. The position of the collar is marked by 27.56 inches. It is advisable to make both collars on either side of a pass the same height. If a neighboring pass requires collars lower in height, the collar is offset between the passes such as *H* in Fig. 36.

Roll diameters like tools which wear are not permanent. They diminish with the progressive wear of the rolls, which must be corrected by dressing. It is usual to put the dimensions of the new diameters of the unused rolls on the roll drawing and to leave it to the roll turner to diminish the diameters accordingly in

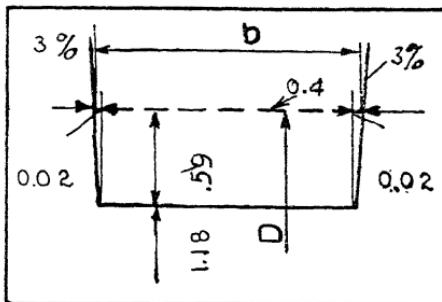


Fig. 37—How a Roll Is Turned Down to Restore Width

old rolls. Assuming that the taper of the pass in Fig. 37 is 3 per cent and the wear of this pass amounts to a maximum of 0.035-inch in width, 1.181 inches must be turned off the roll. As shown in Fig. 37, 1.181 inches diameter requires that the tool should cut in 0.5905-inch. With a 3 per cent taper this gives 0.018-inch on each side or 0.035-inch for the pass.

In Figs. 36 and 39, line marked *NN'* is called the rolling line. It is an imaginary line in the plane of the rolls. To find the roll line of a pair of rolls the overdraft first is determined with the aid of calipers as described of a pass. Pass I in Fig. 38 gives it as $24.016 - 23.622 = 0.394$ -inch. Then the amount of spring is

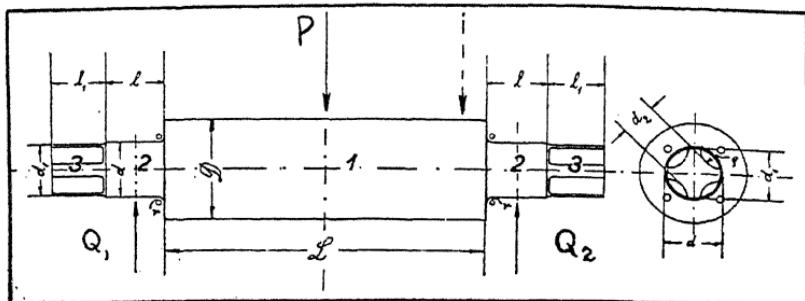


Fig. 38—Diagram of a Roll Showing the Body, Necks, Wabblers, etc.

determined as $0.7 \times \frac{23.622}{100} = 0.165$ -inch. The rolls are laid on the floor or set up on a roll lathe above one another, so that a distance of at least 0.165-inch remains between their surfaces. The distance between the axes then is measured in this position. This would be 24.803 inches with the rolls shown in Fig. 36. The roll line lies so that its distance from the upper roll

axis is $\frac{24.803}{2} + \frac{0.394}{4} = 12.5$ inches and from the lower $\frac{24.803}{2} - \frac{0.394}{4} = 12.303$ inches. These distances are called the average semidiameters; twice these dis-

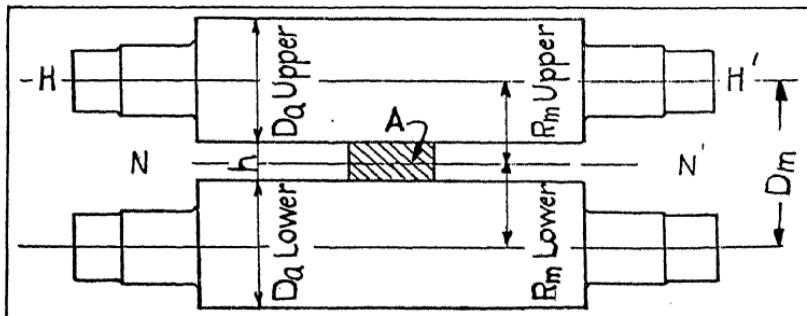


Fig. 39—Method for Determining the Average Diameter of Rolls

tances, or 25 and 24.606 inches respectively, are called the average diameter of the rolls. The average diameter of a pair of rolls or of three rolls placed one above the other is equal to the arithmetical mean of the individual diameters. Symmetrical passes are placed with their center line in the roll line. The latter is many times defined simply as the center of the cut-in passes in the pair of rolls. This definition does not hold for unsymmetrical passes.

Requires Accurate Measurements

All working diameters of the roll are measured with aid of calipers and a scale. The calipers are set by tapping on one of the legs, so that when passing over the place to be measured the resistance is barely felt. The fine touch measurement is a particular art of the roll turner. Two methods are available for determining the average diameter of a roll. The first is with the aid of the roll drawing. In this case one or several of the diameters in a pass or collar are determined. Suppose the rolls, shown in Fig. 36, have been used, and, the diameter of the left outer collar is 26.373 inches and the diameter of pass No. 1 in the lower roll is 22.441 inches. As the drawing shows the roll is 27.559 and 23.622 inches respectively, has been worn 1.181 inches. The average diameter of the lower roll in the present dressed condition is 24.606 inches — 1.181 inches = 23.425 inches.

Then again the average diameter can be determined on the rolls direct. The diameter is measured with the calipers, as shown in Fig. 39, and to this is added the height of the stock *A* to get the average of the upper roll. The average diameter of a roll changes according to the height of the rod rolled. It is customary to determine it for a single rod and for the smallest rod rolled with the particular roll. Suppose in this case, the height of the rod is 0.157-inch and *Da* upper = 9.843 inches, *Da* lower = 9.449 inches. The

average diameter of the upper and lower then can be determined as $9.843 + 0.157 = 10$ inches for the upper and $9.449 + 0.157 = 9.606$ inches for the lower roll.

A roll with cut-in passes has different diameters in the passes and on the collars as shown in Figs. 36 and 40. The height of the profile to be rolled, which determines the average diameter, is not known, or if it is, it is not always clear as to where the middle line of such an irregular pass is located. In such cases the average diameter can be determined only with the aid of the upper or lower roll belonging to the pair of rolls. The foregoing shows that the distance between the roll axis in the instance of the passage of the stock through the rolls, increases and decreases respectively in an

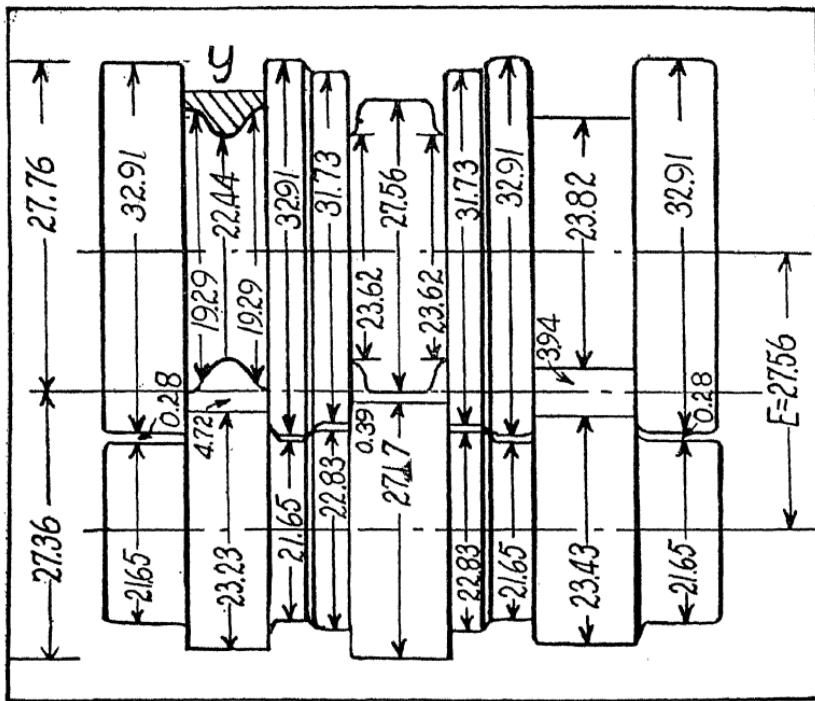


Fig. 40—Method for Determining the Average Diameter of a Designed Roll

amount equal to one-half the over or underdraft. Assuming the distance, E , in Fig. 40 amounts to 27.559 inches and the overdraft 0.394-inch, then the average diameter of the upper roll equals $27.559 + 0.197$ or 27.756 inches and of the lower $27.559 - 0.197$ or 27.362 inches. As it is difficult to measure the distance between the axes, it is advisable to begin with the diameter of the collars instead and to estimate the spring at about 1 per cent of the average diameter. We then have at the right of Fig. 40:

$$E = \frac{32.913}{2} + \frac{21.654}{2} + 0.276 = 27.56''$$

The overdraft can be determined from the adjacent pass as $23.819 - 23.425 = 0.394$ -inch and the average diameter of the upper and lower roll is determined from this as previously mentioned.

If the height of a pass and the position of its middle or neutral line is known, the average diameter of the upper and lower roll can be determined from the working diameter as the sum of the latter and the height of the pass h . For example, at the right in Fig. 40, $h = 3.937$ inches and the distance of the middle or neutral line of the roll equals 1.969 inches. Therefore,

$$D_{m\ upper} = 23.819 + 3.937 = 27.756''$$

$$D_{m\ lower} = 23.425 + 3.937 = 27.362''$$

If a roll has different overdrafts, it also has different average diameters. If on the contrary the former is the same for the whole roll, the average diameter also is the same. If the average diameter of the existing rolls is determined in the foregoing manner, it can be chosen in the case of newly contemplated roll trains. The average diameter is the most important determination, which must be made for a new roll train. It either can be chosen from existing roll trains or from tables as given in Huette's *Handbook for Iron and Steel Engineers*, 1922 edition, page 768. The body of the roll, about three times the diameter, can be chosen from the same tables and the neck and wabbler determined

Table I

Dimensions for Roll Necks and Wabblers

Kind of rolls	l	d	r	d_1	l_1	d_2	ϵ
Heavy sheet	$0.8d$	$0.68D$	$0.1d$	$0.94d \div 0.954$	$0.6d_1 + 1.575''$	$0.66d_1$	$0.3d + 0.394''$
Light sheet	$0.8d$	$0.74D$	$0.1d$	$0.94d \div 0.95d$	$0.6d_1 + 1.575''$	$0.66d_1$	$0.34 + 0.394''$
Rod and merchant	$d + 0.787''$	$d + 1.969''$	$0.55D \div 0.55D$	$0.94d \div 0.95d$	$0.5d_1 + 1.575''$	$0.66d_1$	$0.3d + 0.394''$
Miscellaneous	$0.9d + 0.787''$	$0.54D \div 0.58D$	$0.1d$	$0.94d \div 0.96d$	$0.6d_1 + 1.575''$	$0.66d_1$	$0.3d + 0.394''$

from a table in the same handbook. The latter data using Fig. 38 as reference are shown in Table I.

Where such tables permit a certain leeway for the diameter it should be remembered that rolls of large diameter consume much work when running light. In addition large rolls spread more and elongate less than small rolls, as previously mentioned. Where it is not a question of spread, as with roughing rolls, an additional amount of energy is required. Under similar conditions with a large roll diameter the upsetting effect, and therefore the slip between the rolls, is larger. From the standpoint of the stretching effect and the power necessary for it, small rolls are more advantageous than large units. If considerable spreading is desired, as with hoops, skelp and many broad shapes, the diameter is carried to the upper limit. This is also the case, when rolling difficult shapes with unlike working diameters because the release stresses increase as the average diameter of the roll decreases. For this reason with beam and U-profiles the error is larger if the diameter is chosen too small, than if it is chosen too large. If the diameter is chosen to prevent roll breakages, it becomes a question of the calculation of the strength necessary. It is then proper to begin with the determination of the dimensions of the neck.

A roll as shown in Fig. 38 consists of the roll body, 1, which contains the passes; the two necks 2, which rest on the bearings; and, the wabblers 3, which serve to couple it with the adjacent roll. Rolls are subjected to torsional stresses, but as the necks are not broken by this as far as is known, it can be disregarded. The roll diameter must be chosen larger than corresponds to the torsional strength for rolling reasons. Rolls also are subjected to bending, and the body is stressed the most, when the roll pressure, that is, the force, which on the passage of the stock through the rolls in the center, attempts to push the upper roll up and the lower roll down. In the first case the so-called bearing reac-

tion, that is, the forces Q_1 and Q_2 with which the bearings press on the necks and prevent the rolls from moving either down or up, are equal to $P \div 2$. In the latter case the bearing pressure Q_2 next to the edge where the force is located almost equals P . In one case the roll body must satisfy the equation:

$$P \times \frac{L + l}{2} = W_b \times k_b \quad (4)$$

where W_b is the section modulus of the body equal to $3.1416D^3 \div 32$, and k_b the permissible bending stress. For soft and chilled rolls k_b can be taken as 1422 and 2844, for cast-steel rolls as 9954, for forged as 12,798 pounds per square inch. Ultimate strength is about five or six times as large. If, on the contrary, the roll pressure is applied at the end, the neck is the part endangered. It must satisfy the equation,

$$P \times \frac{l}{2} = W_z \times k_b \quad (5)$$

W_z equals section modulus of the neck equals $3.1416D^3 \div 32$. In addition the average pressure per square inch of the neck cross section should not rise above a certain amount. The necessity for designing the necks with regard to strength and the high roll pressures and still not make the housing too large, leads to specific pressures up to 7110 pounds per square inch in roll trains. This accounts for the considerable heating of the necks and the necessity for cooling them with water. It is desirable not to go above 2133, at the most 2844 pounds per square inch. These surface pressures are understood as being distributed over the whole horizontal projection of the neck ($l \times d$). Actually the bearing presses from 60 to 80 per cent around the neck. The average surface pressures, therefore, are considerably higher.

The Fink formula on page 964, *Iron Trade Review*, Oct. 15, 1925 (predecessor of STEEL) makes it possible to determine the theoretical work necessary for a pass. It is A foot-pounds. As was previously shown, up to

30 per cent must be added for the slip between the entrance and exit of the stock. This sum is the total theoretical roll work and equals A_t foot-pounds. Work is always the product of a force multiplied by the distance through which it acts. Therefore, it may be considered as consisting of the roll pressure P times the length of the stock after the pass s_2 .

$$A_t = P_t \times s_2 \text{ or } P_t = \frac{A_t}{s_2}$$

If the foregoing calculated theoretical value is set at 1422 pounds per square inch, the Puppe tests on neck pressures result in values from 1635 to 2844 pounds per square inch. Much of the difference between the actual and the useful work figured from the neck pressures consists of neck friction, which does not influence the roll pressure. If 100 per cent of the foregoing theoretical roll pressure is added to that determined previously the result will not be favorable and, therefore:

$$P_{\text{eff}} = 2P_t = 2 \frac{A_t}{s_2}$$

The numerical determination of the dimensions of a roll based on the strength of the necks and the body according to the foregoing follows: The size of the largest ingot cross section to be rolled equals 9.843 inches x 9.843 inches; the draft equals 15 per cent; the rolling speed equals 7.55 feet per second; the elastic limit in compression equals 14,220 pounds per square inch, the roll work per second according to the foregoing then:

$$\begin{aligned} A_{t \text{ sec}} &= 1.3^* \times 9.843 \times 9.843 \times 7.55 \times 14,220 \times l_n \quad 0.85 \\ &= 13,510,000 \times l_n \quad 1.17 \\ &= 25,939,000 \text{ inch pounds} \\ \text{or} \quad &\frac{25,939,000}{7.55 \times 12} \quad 573,000 \text{ pounds} \end{aligned}$$

*Maximum 30 per cent addition for slip, according to Fink.

The most unfavorable case for the neck is when this force is applied totally at the edge because the neck on that side will have to carry nearly all the load. If the neck length is assumed to be equal to the diameter and if 2844 pounds per square inch is considered to be the permissible surface pressure, then:

$$d^2 : \frac{573,000}{2844} \text{ or } d = 14.2 \text{ inches}$$

According to strength the neck diameter would be de-

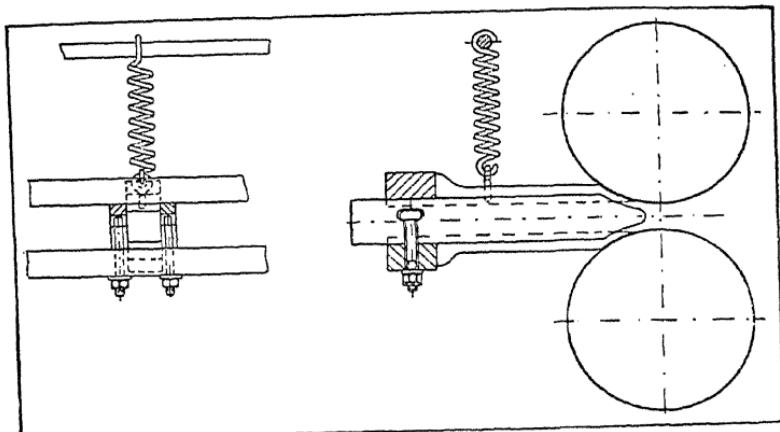


Fig. 41—Rolling Beam to Which the Cast-Iron or Forged-Steel Guides Are Fastened by Wedges

termined by equation 5, page 54:

$$\times \frac{l}{2} \quad \frac{3.1416 d^3}{32} \times k_b$$

Again l is equal to d and material is assumed to be a forged steel casting, as is the custom for blooming mill rolls, therefore $k_b = 12,798$. According to this:

$$573,000 \times \frac{d}{2} \quad \frac{3.1416 d^3}{32} \times 12,798$$

$$d = 15.23 \text{ inches}$$

The diameter of the roll body is found, if L is chosen $= 3D$ and if for simplicity of calculation $l = 0.55$, D

$= 0.18L$ substituted primarily from the table in Huette, from equation 4*.

$$573,000 \times \frac{3D}{32} (1 + 0.18) \times \frac{3.1416 D^3}{32} \times 12,798$$

$$D^2 : \frac{573,000 \times 3.54 \times 32}{4 \times 12,798 \times 3.1416} \text{ approaches } 403$$

$$D \text{ approaches } 20.1 \text{ inches}$$

This is not the average diameter, but the smallest working one, below which the roll should not be permitted to go even after ensued wear. For wear 10 per cent is added.

Therefore, the average diameter is $D_m = (20.1 + 0.85 \times 9.843) 1.1$ approaches 31.3 inches. In practice for the proposed purpose, considerably smaller diameters are chosen for the body and the necks. This is justifiable if one considers that the value of $k_b = 12,798$. The foregoing substitutes give a safety factor of at least 5, while with an interchangeable tool, as the rolls represent, the worst case would be satisfied with a factor of 2. The diameters for roll bodies therefore would be $31.3 (\sqrt[3]{2} \div \sqrt[3]{5}) = 22.8$ inches and for necks $15.23 (\sqrt[3]{2} \div \sqrt[3]{5}) = 11.2$ inches which is about the usual minimum in practice. The roll pressure so calculated also can be employed for the calculation of the roll housings.

How Guides Are Held

Guard or stripper guides are fastened sidewise by the so-called guides made of cast iron, forged steel or hardened steel plates, which are fastened by wedges or are screwed down to a cross piece called the rolling beam in front of the rolls. This is shown in Fig. 41. Such guides make the pass easily known to the roller, into which he should enter the stock. If the guides are left in place, even if the particular pass is not being used for a time, it can be plugged with wood so that it will be impossible to enter the stock into the wrong pass.

Guides direct the stock in the way it should enter

*Frequently L will depend on the pass to be placed on the roll.

and leave the rolls. In the first case they are called entrance, in the latter, exit guides. With high-speed mills, the steel toward the end of the passage swings or whips back and forth and would sometimes run more to one side and sometimes more to the other; if the guides did not lead the steel centrally into the pass it would be unequal in its dimensions. At the exit the guides are necessary, so that if there is any irregularity, such as un-

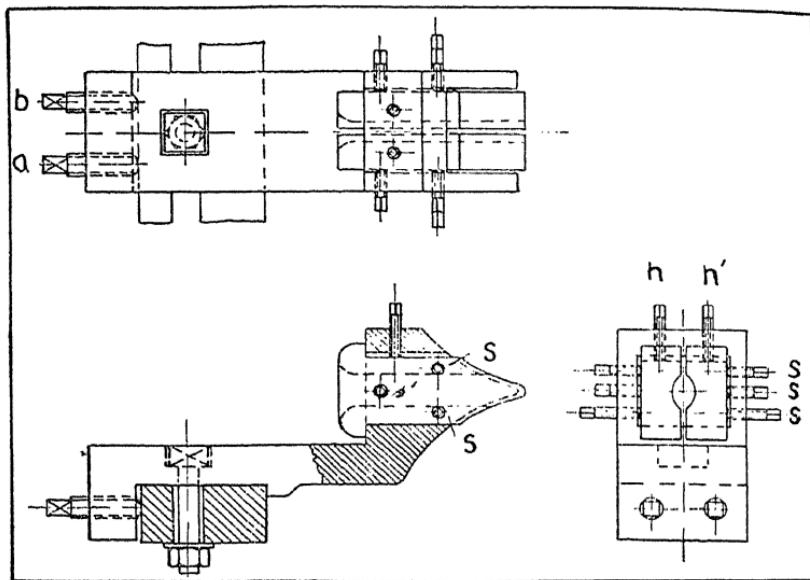


Fig. 42—Guide Box Used for Holding Split-Type Guides When Rolling Small Shapes, Rounds and Squares

even temperature, the stock will not leave the rolls crooked and endanger the crew standing at the mill.

If it is necessary with guides to make an accurate adjustment in the vertical and horizontal direction, as with squares and rounds, small shapes, etc., the guides are made in two pieces, called guide-halves. These are held by the guide box, shown in Fig. 42, and must be made adjustable in the vertical direction by the screws *ss* and *hh'* by shimming it up with plates under the

guides. In addition it is advisable to pivot the whole box up and down and to both sides. The latter is accomplished by tightening screw *a*, if a right turn is desired and *b* if a left turn. For the up and down movements either the roll beam, to which the guide box is fastened and which in turn is fastened to the housings, can be moved up and down, or setscrews similar to those on the guide box can be used.

The square type of guide in addition to directing the steel exactly centrally into the groove, has to prevent it from turning. With small shape passes, such as small angles, which have a tendency to turn in the pass or

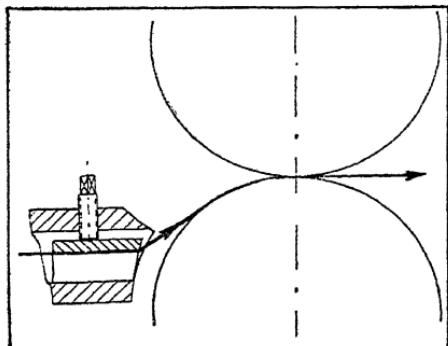


Fig. 43- -Type of Hook Guide Which Prevents the Piece from Turning in the Pass

to climb on one side, hook guides must be used. Their effect can be intensified considerably if the guides are pushed down. The stock upon entering the rolls is stretched tightly, as shown in Fig. 43. Many small profiles cannot be rolled successfully without this arrangement. If stretching causes the stock to tear, the guide is raised to a slightly higher position. It must not be installed too near the rolls, because gripping would then be impossible.

Finally, guides can have the following duty: instead of the rod to be rolled being gripped by the tongs of the roller, or by the catcher or passer and entered

into the next pass, the piece is entered by the guide. Such an arrangement, which is an exit guide for one set of rolls and the entrance for another, is called a repeater. The difficulty, in this case, is not so much in the changing of the rolling direction 180 degrees from one set of rolls to another or with 3-high rolls from the lower to the upper, as shown in Fig. 44, but is as follows: The instant the stock strikes the next roll designated 2 in Fig. 44 it must be given the opportunity to jump from

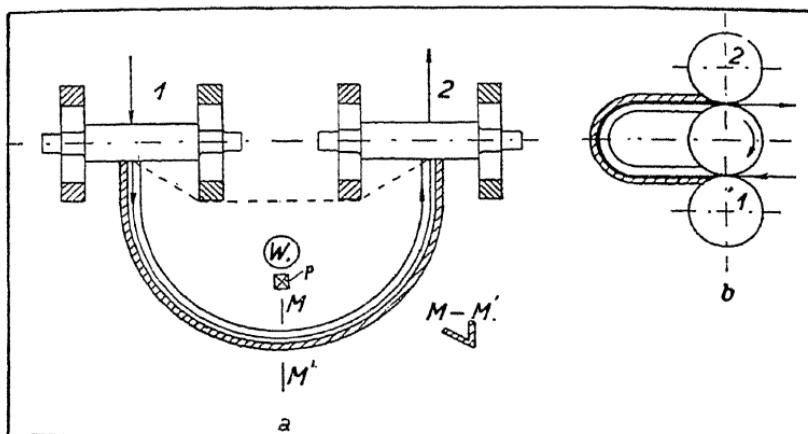


Fig. 44—Loop-Type Guides Are Shown at *a* and *b*. The Post, *P*, Protects the Roller in Case the Loop Becomes Smaller

the trough, because the draft is difficult to regulate so that the rolling speed at 1 and 2 are exactly equal. The reason for this is that the elongation depends on the temperature more or less, which always produces differences in the stock. If such a regulation was tried, the speed of the rolls at stand No. 2 would be found higher sometimes and lower at other times than the No. 1 stand of rolls. In the first case the loop would get smaller, it would then be pulled in against the housings as shown by the broken line in Fig. 45, a case, which sometimes occurs if roll 1 for any reason should stop suddenly and which exposes the roller standing between

the stands to danger. This is prevented by placing a post, P , in the floor in front of the position of the roller, W . Ordinarily the loop should not be drawn in at the beginning. This is accomplished by making the draft at stand No. 2 so that the stock will enter at a lower speed

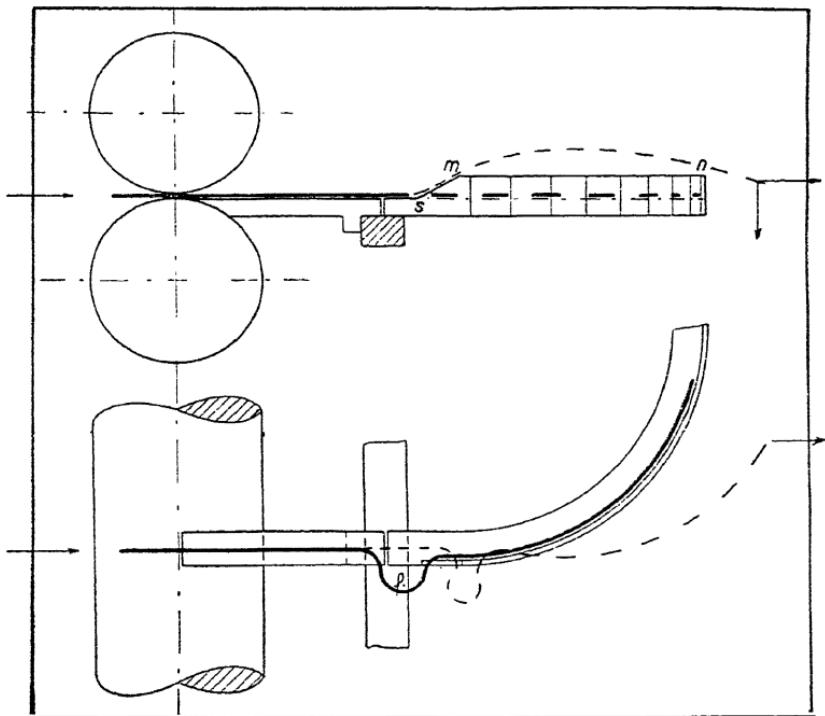


Fig. 45—Opening and Incline of a Loop Guide Which Finds Wide Application on Rod Mills

than it leaves the rolls of the No. 1 stand. The loop, therefore, is enlarged when rolling.

This can only happen after the loop has come out of the trough, as the length of the trough remains the same. To handle the loop the troughs are made either angular or a U-shape. The former open down, the latter open either up or down. When the rod hits roll No. 2,

its speed is retarded. As roll No. 1 continues to eject material, the rod folds itself and either falls out of the trough toward the floor or jumps over the guiding leg under the influence of the steel pushing itself ahead. For this purpose the guide begins with a slope about 13.78 inches behind the roll as shown in Fig. 45. In this hole, about 13.78 inches in length a fold, *f*, is formed when the stock strikes roll No. 2, which under the influ-

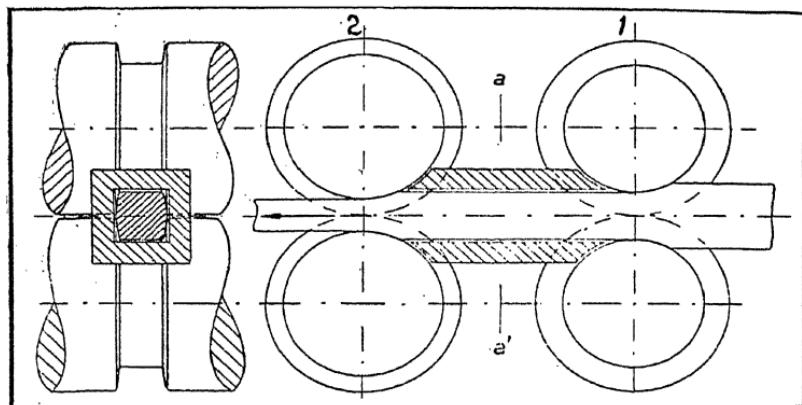


Fig. 46—Tube Guides of This Type Frequently Are Used with Continuous Mills

ence of the material pushing from behind is pushed up the slanting plane at *s*. The loop wiggles over the edge of the trough *mn* and falls on the floor, clear of the trough.

Tube guides are used with continuous type mills as shown in Fig. 46. The relation of different speeds to guides as previously mentioned, applies to the tube-type unit also. In continuous mills, however, the stock passes into roll stand No. 2 faster than it leaves the rolls in the No. 1 stand. The rod or billet is drawn from 2 to 3 per cent. Due to this a slip occurs in roll 1 and 2 and, therefore, more energy is required. On the other hand this drawing increases the stretching effect of the rolls, so that a part of lost power is made up. If the tube

guide is given a twist, it can also be used to turn the stock 45 or 90 degrees. Pipe guides also are used in wire drawing departments to lead the wire from the finishing dies to the reels.

The guides shown in Fig. 44b were designed by Schoepf and were developed for the case shown in Fig. 44a. They are constructed substantially for the reason that recurring impact effects are dissipated by large masses, which almost use up the impact before it is transmitted to the connections. Similar effects arise when holding a heavy hammer against the rivet in riveting or with the anvil of a steam hammer.

The design of a pass must be such that the stock will go through the roll without turning, and the slope of the exit plane such that it leaves the rolls with the desired twist. To turn the steel to the left with the pass, but to the right with the entrance guide, or to give a twist to the right with the exit plane, but to force a left twist with the loop through, is difficult to accomplish.

The speed of rolling is understood the speed in feet per second, with which the rolled material leaves the rolls. In practice the rolling speed is determined by using the average diameter. If the diameter for a mill equals D_m , the rolling speed is taken as $v = (D_m \times 3.1416 \times n) \div 60$ where n is the number of revolutions of the rolls per minute. In the investigations of bar acceleration, that is the difference between the rolling speed and the circumference speed of the rolls, the rolling speed is referred to as the working diameter. E. Blass, E. Cotel and F. Puppe measured the bar acceleration by putting marks on the surface of the roll and comparing their distance with the corresponding marks on the rolled material.

They concluded that as the marks on the roll as shown in Fig. 47 covered a shorter distance in the same time than those on the rolled material the latter must leave the rolls with a greater speed than is denoted by the circumference speed it must accelerate. This con-

clusion would be correct only if the rolls had an infinitely large radius. The smaller the radius the more the distance E must lengthen if the rolled rod leaves the perpendicular to the plane of the rolls. E must become longer than e , in the instant of passage through the line OO' even if there is no bar acceleration. The upper and lower fibers of the stock stretch themselves by this straightening, while the center are upset and with equal roll diameters the neutral fibers are at a distance

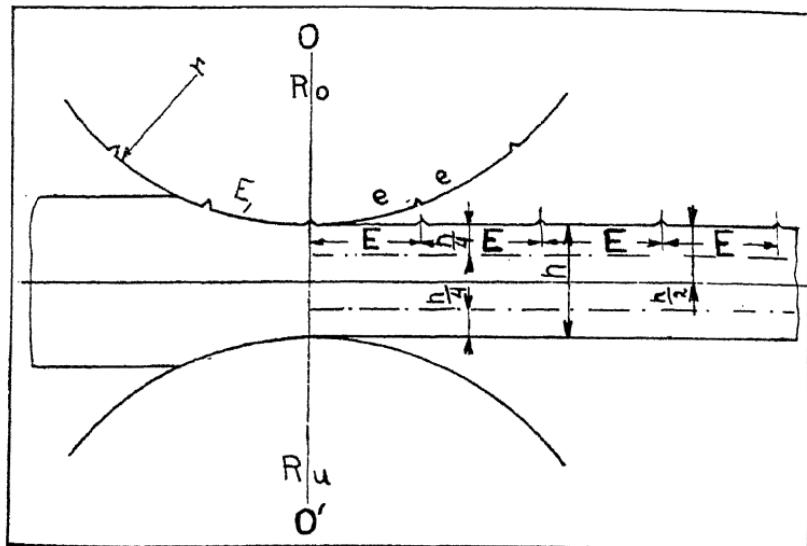


Fig. 47—Diagram Showing the Difference Between the Rolling Speed and the Circumference Speed of Rolls

equal to $h \div 4$ from the roll surfaces. This could be shown if half of the rod would wrap itself around the upper and half around the lower roll, provided the stripper guide and the internal adhesion of the two halves did not prevent. That a rod when passed between two rolls of equal diameter without a stripper guide divides in the center and bends up and down, can be proven if a thin sheet made of separate lead lamellæ is passed between rolls. The exit speed then is increased in the relation

of the circumference speed of a circle with the radius $R + (h \div 4)$ to the radius R , that is in an amount equal to $1 + (h \div 4 R)$. It therefore is not a question of the difference between the speeds of the roll surface and the stock. With equal working diameters and normal conditions, the neutral fibers as a rule leave the rolls with a corresponding speed and only the outer fibers are stretched when bending them straight. This determination is important, because it is possible to de-

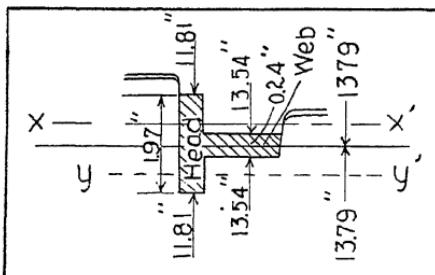


Fig. 48—T-Section Showing the Slip with Different Working Diameters

termine in advance, the speed gain with periodic profiles where it plays only a practical part. In addition the rolling speed is not calculated from the working nor from the average diameter, but is calculated from a diameter that lies between the two. In practice for the sake of simplicity the value determined with the average diameter may be retained as a value approaching nearly the rolling speed.

Finally, the knowledge of the bending of the stock on leaving the rolls gives a simple hint for the cases in which a pass shows different sized working diameters. The tee in Fig. 48 for example has a working diameter of 11.811 inches at the head and of 13.543 inches at the web. In the first case the small particles of matter touching the rolls if free would have a speed of $11.811 \times 3.1416 \times n \div (60 \times 12)$, while in the latter case the speed would be $13.543 \times 3.1416 \times n \div (60 \times 12)$.

Since the individual parts of the profile are connected, it is impossible for them to move with different velocities. The stock in the head rushes forward in comparison to the working roll surface; in the web it slips backwards on the roll surface. This slip and the fractional work it consumes, is one of the reasons why the power necessary in rolling shapes of different working diameters is larger than when rolling simple shapes.

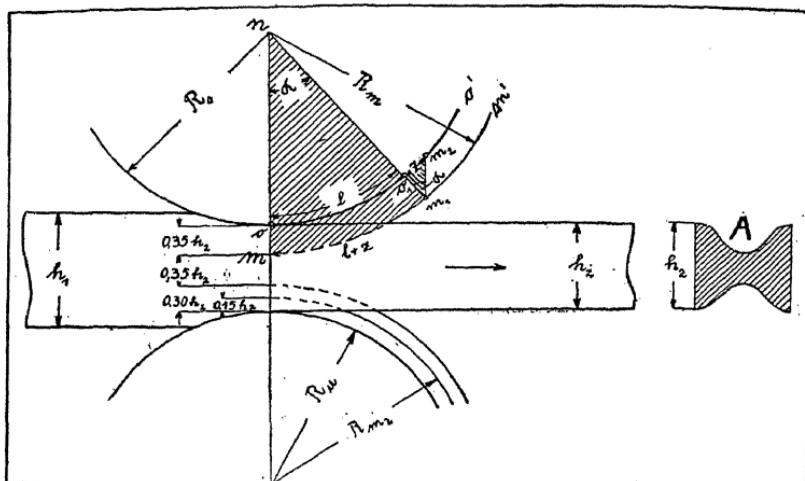


Fig. 49—Diagram Showing the Pulling to Which the Outer Fibers of a Profile Are Subjected During Reduction

The same conclusion is reached if the two halves of the tee, Fig. 48, in the neutral fibers XX' and YY' are bent up around the corresponding roll radius before leaving the roll and are considered straightened. The upper and lower ends of the head experience an increased speed, a pulling along, the inner parts of the profile a diminished speed, an upsetting. The pulling will express itself at that place by shrinkage and crevasses. Or stresses may be caused after the rolling, which in further working of the stock may lead to defects. Such appearances may be prevented because more draft is given these parts of the cross section than is drawn away

by the bending when the stock leaves the hot mill rolls.

The determination of the position of the neutral axes XX' and YY' in Fig. 48 requires additional information. If the pass has overdraft the neutral fibers are near the center of the rod. The limits must be at least a distance equal to $h_2 \div 4$ from the upper fibers if the diameters are equal; and at most $h_2 \div 2$ if the overdraft is so large that both halves of the profile have the tendency to wrap themselves around the smaller lower roll. With the design of periodic profiles the author found in most cases that the neutral fibers with the normal relation of the overdraft to the roll diameter about 3 per cent was $0.35h_2$ from the upper fibers, therefore almost half way between $h_2 \div 4$ and $h_2 \div 2$. This value is the basis of the practical use of the bending theory. The pulling, which the outer fibers of a profile A shown in Fig. 49 of the height h_2 experience in passes through rolls having the working radii R_o and R_u where R_o is greater than R_u , is calculated as follows:

The pulling along, Ze , is denoted as the relation between the increase in length, z , of one of the outer fibers, to its length after the pulling along, $l + z$, in Fig. 49. Therefore $Ze = z \div (l + z)$. The outer fibre oo_1 of the length l , when bent on the circumference oo' with the radius R_o , must assume the length of the neutral fibers mm_1 when bending them straight. The difference between mm_1 and l is therefore the linear pulling along z in which m_1m_2 is parallel to mo .

If the arcs l and z are small then from the similarity of the two hatched triangles nmm_1 and $m_1o_1m_2$ whose acute angles α correspond, the following is derived:

$$R_m : (l+z) = (R_m - R_o) : z$$

Without overdraft: $R_m - R_o = h_2 \div 4$.

With overdraft, as previously mentioned, $R_m - R_o$ equals $0.35h_2$ or approaches $h_2 \div 3$.

$$z = \frac{(l+z)(R_m - R_o)}{R_m} = \frac{(l+z)h_2}{4R_m}$$

and in the latter case,

$$z = \frac{(l+z) h_2}{3R_m}$$

The value substituted in the foregoing formula for Ze gives for the pulling along when the rolls are of equal size:

$$Ze_1 = \frac{h_2}{4R_m} = \frac{0.25 h_2}{R_m}$$

when the overdraft is normal the substitution gives:

$$Ze_2 = \frac{h_2}{3R_m} = \frac{0.35 h_2}{R_m}$$

The pulling along, which the outer fibers of a pro-

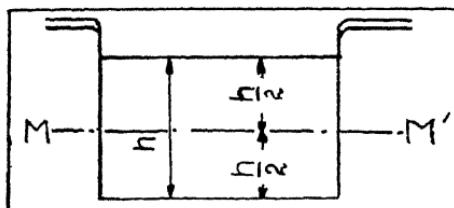


Fig. 50—Arrangement of the Neutral Line with Rectangular Passes

file experience on emerging from the rolls, increases with the height of the stock and decreases with the diameter of the roll. Due to the underdraft of the lower roll, the following formula applies:

$$R_{m2} - R_u = 0.15 h_2$$

therefore,

$$Z_u = \frac{(l+z) 0.15 h_2}{R_{m2}} \text{ and } Ze_u = \frac{0.15 h_2}{R_{m2}}$$

From this the correction of the draft can be determined, which will have to be given the upper and lower parts of the profile, if the pulling along at the exit from the rolls is to be compensated by a corresponding increase in draft. For the head top part of the T-profile in Fig. 48 it amounts to:

$$Ze = \frac{0.35 \times 1.969}{5.906 + (0.35 \times 1.969)} \text{ or approaches 10 per cent}$$

If the profile is to go through the rolls without stress, the head end must be given 10 per cent more draft than the web, to compensate for the pulling along, or the different rolling speeds. If the web, for example, has a 20 per cent draft, the upper part of the head should receive 22 per cent. The roll line as previously mentioned always cuts the pass. The cutting line of both rolls is designed as the neutral line as only with symmetrical profiles does it go through the center of the pass. The roll line is unmovable if the distance between roll axes and the over and underdraft is given. It does not arrange itself according to the

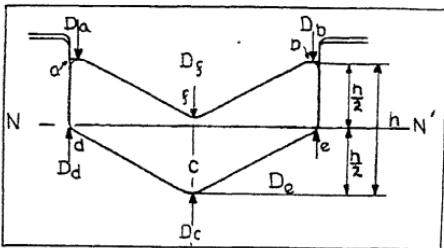


Fig. 51—Layout of a Pass Showing the Neutral Line with an Angular Pass

passes. For round and oval passes the neutral line is the horizontal diameter, for squares mostly the horizontal diagonal while for rectangular cross sections the parallel line in the center between the horizontal rectangular sides as indicated by MM' in Fig. 50.

For determining the neutral line for shapes the pass is drawn about as it should lie in the roll, and the two outermost points, a and b in Fig. 51, are connected by a line. A parallel line then is drawn through the third outermost point, c , lying on the other side of the sought neutral line, and in the center between the two a second designated NN' as the sought neutral line. It divides the total height h of the pass equally. If a template is made the height h can be measured with a caliper square. The neutral line is then drawn paral-

lel to the line ab a distance $h \div 2$ away. If it is laid into the roll line, the parallel ab also will lie parallel to this latter. The roll diameters D_a and D_b at the highest points a and b will be equal, and the amount of the overdraft larger than the diameter D_c at the lowest point c . Assuming the average diameter of the top roll is 23.62 inches, of the bottom 23.03 inches, the overdraft is thus 0.59-inch, h is 3.15 inches, therefore

$$D_a = D_b = 23.62 - 3.15 = 20.47$$

$$D_c = 23.03 - 3.15 \text{ or } 20.47 - 0.59 = 19.88 \text{ inches}$$

The position of the neutral line determined in this way is the best for a pass, whose working surfaces in the main are not parallel to the roll line. If this is done, the stock leaves the rolls straight, while if D_a and D_b are not equal, it has a tendency to turn sidewise.

Neutral Line Is Standard

If on the other hand the working surfaces are parallel to the roll line and the profile can be divided into several rectangles the neutral line of the broadest rectangle, 4, 5, 7, 8 in Fig. 4 is found in the same manner as in Fig. 50, and is taken as standard for the whole pass. Or, if in Fig. 52, the neutral lines of the single rectangles oo' , nn' and o_1o_2 are far apart, the neutral line NN' for the whole lies through the center of grav-

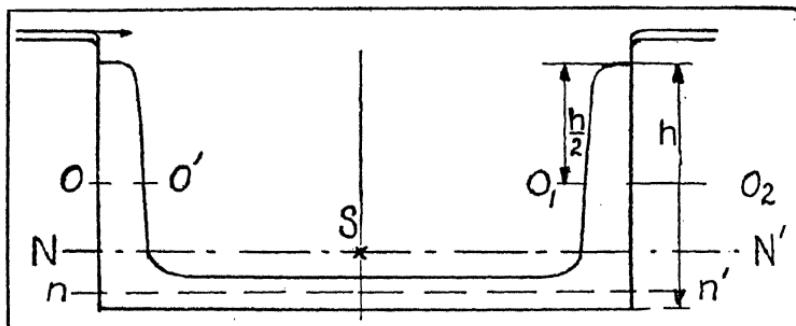


Fig. 52—If the Neutral Lines of Single Rectangles Are Far Apart, the Neutral Line for the Whole Lies Through the Center of Gravity of the Pass

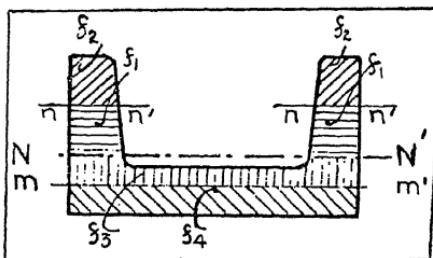


Fig. 53—Oblique Lined Surfaces Have Been Pulled Along; the Inner Surfaces Are Upset

ity of the pass. This is an old rule of thumb method.

The position of the pass, or its neutral line has nothing to do with the center of gravity. The correctness of the rule becomes apparent when considering the theory of the bending off of the stock on leaving the rolls and of the pulling along which the outermost fibers experience. If in Fig. 53 the neutral line NN' passes through the center of gravity, there lies above and below it the same amount of surface, that is, half of the cross section. The horizontal and the sloping lined areas lying above f_1 and f_2 are equal to the vertical and sloping lined areas lying below f_3 and f_4 . If the bending of the surface f_1 , f_2 and f_3 , f_4 also results according to their center of gravity lines nn' and mm' respectively, as much surface is pulled along as is upset. The sloping lined areas are pulled along, the perpendicular and horizontal lined areas are upset. Accordingly as much material will be missing in the former, as will be in excess in the latter. The compensation, that is, the flowing, therefore, will be completed within the pass while the rolling stresses in the longitudinal direction will be a minimum.

Another method based on the difference of the speeds is that the neutral line of the whole pass does not go through the center of gravity, but is so located among the neutral lines of the individual cross sections, that its distance is divided in relation to the working

surfaces of the pass. In Fig. 54 the hatched trapezoids, which go to make up the profile, first are changed into equivalent rectangular sections and the inner q_3 lengthened to connect with the two outside sections q_1 and q_2 . In other words, the profile is divided into three rectangles q_1 , q_2 and q_3 . The neutral line for q_3 is NN' for q_1 and q_2 MM' . The distance between them is 0.71-inch because the line mm' lies 0.98-inch higher than the bottom line of the profile while NN' is only 0.27-inch. The neutral lines of the cross sections are the difference apart that is, 0.71-inch. That of the whole cross section XX' must divide the distance in relation to the working surfaces, that is, in relation of $40 : (2 \times 10)$ or $2 : 1$, and in such a manner that it lies nearer the neutral line of the rectangle NN' , with the larger working surface. With the described method the individual rectangles come into their rights with their neutral lines, as they possess working surfaces, that is, they are in touch with the working surfaces, of the rolls. If the center rectangle were the same width, as the outer taken together, XX' would be half way between MM' and NN' .

For example, if a definite overdraft 0.3937-inch and the distance between the axes of the upper and lower rolls is 19.88 inches then the average diameter of the upper roll is 20.08 inches and of the lower roll 19.69 inches. These values are permanent, regardless of the method used to determine the neutral line of the pass. If the neutral line as found by the first method is placed in the roll line, the normal overdraft, 0.3937-inch, will result for the outermost points of the pass. With angles and similar profiles this method works satisfactorily. Excessive working diameters, which do not correspond, cause excessive slip and, therefore, high-rolling resistance and high-power consumption.

This is wholly different with passes as in Fig. 54. In this case if the neutral line bisects the pass height,

with an upper roll diameter of 20.08 inches and a lower of 19.69 inches, only the outer rectangles receive the normal overdraft. In the aggregate they touch the working roll surface in a width of 0.787-inch. On the lower side, the roll diameter is $19.69 - 1.97 = 17.72$ and on the upper $20.08 + 2 (2.04 - 1.61) = 20.94$ inches. The overdraft, 3.22 inches, therefore, is exces-

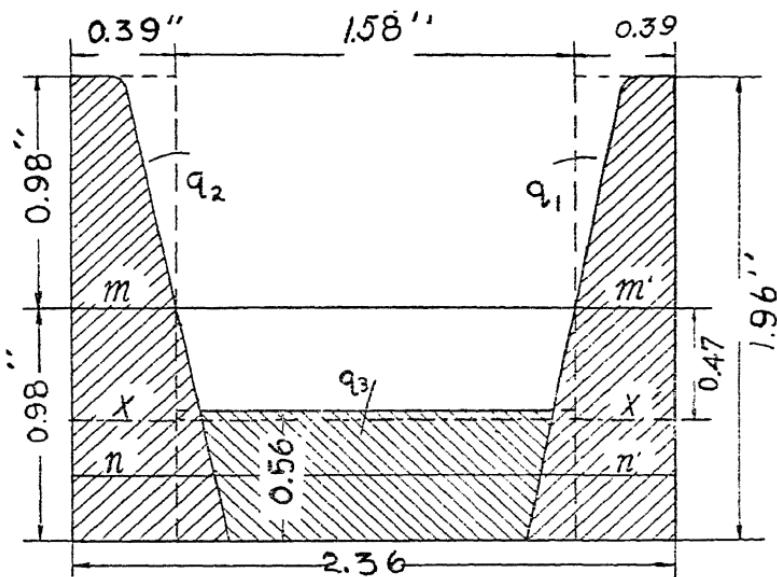


Fig. 54—Diagram Showing That with Different Speeds the Neutral Line of the Entire Pass Does Not Go Through the Center of Gravity

sive and the material to be rolled will be stressed considerably. The roll surface speeds at the upper and lower rectangle sides have the relation $20.94 : 17.72$. The stock will attempt to assume the larger rolling speed of its upper rectangular side and will drag along the lower roll. This is possible to a certain degree. In fact the upper and lower rolls are coupled together by gears with the same number of teeth. These transmit the power through coupling spindles and boxes through

the train of rolls. Wabblers, spindles and boxes have a play, which may be equivalent to half a revolution. The bottom roll in this case will be ahead of the center pinion, which drives it. At the instant the stock leaves the mill the upper and lower rolls are independent of one another. The carrying action of the lower roll, therefore, will stop. This unit stands until the play is covered by the coupling boxes and spindles, to be suddenly set into motion again. This occurs with an audible blow, which goes through the whole train, and which puts considerable stress not only on the wabblers

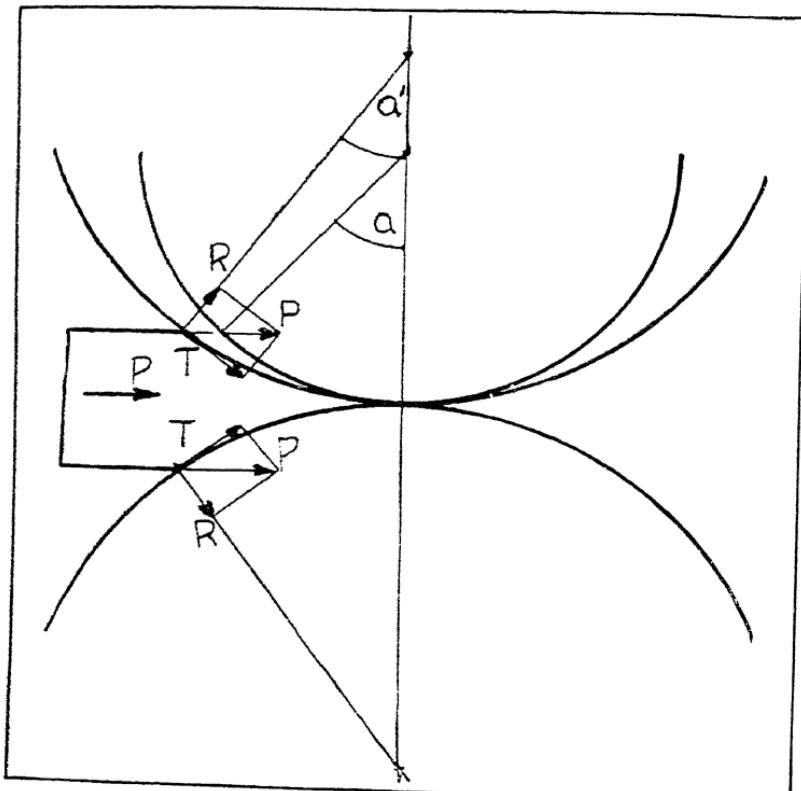


Fig. 55—Rolls No Longer Grip with Excessive Draft. The Gripping Properties Decrease as the Roll Diameter Decreases

and spindles, but also on the pinions and other driving parts.

If the neutral line, therefore, is placed so that the pulling along becomes small, heavy blows in the train result and vice versa. Pulling along and impact becomes more intensified the smaller the average diameter is in relation to the pass height. As previously mentioned pulling along decreases with increasing diameter. The same is true for the difference of the diameters when 7.87 inches is turned off. The relation of the speeds is then as 13.07 : 9.84 instead of as stated 20.94 : 17.72. For most shapes it is better to choose roll diameters too large than too small. Profiles of this type rolled on a 20-inch mill, can be worked without difficulty, while the same pass placed on a 12-inch mill does not permit a piece to leave the rolls satisfactorily.

Stresses in the single cross-sectional parts of the stock arise in the rolling process because of the different draft in the individual parts; and the percentage difference of the working diameters among themselves, and of the working diameter on the one hand and the average diameter on the other. The latter stresses, which result from the straightening of the stock on leaving the rolls, occur with every shape of the pass.

Stress Causes Equalization

Where stresses are set up, there is also the tendency for equalization because those parts of the cross section, which are given too much draft or thrown out ahead more by the larger roll diameters, give off material to those with less draft. Equalization also occurs with shapes because the material remaining behind shrinks; or it will result because of the slippage between the roll and the stock. The tendency toward shrinkage increases the more the flow is prevented.

An important rule for roll pass design is that the desired change of shape be made in as few passes as possible because the smaller their number, the shorter will be the rolling time and the cooling of the stock and

the lower the power consumption. A small number of passes will require a large reduction of cross section.

The larger the draft, the more irregular will be the finished dimensions of the rolled piece. The material spreads unequally, and the spring increases and varies with small changes in composition or temperature of the material. Consequently, the thickness of the rolled product will be irregular. Therefore, sufficient draft in the finishing pass should be used so that the stock will be drawn through and leave the rolls

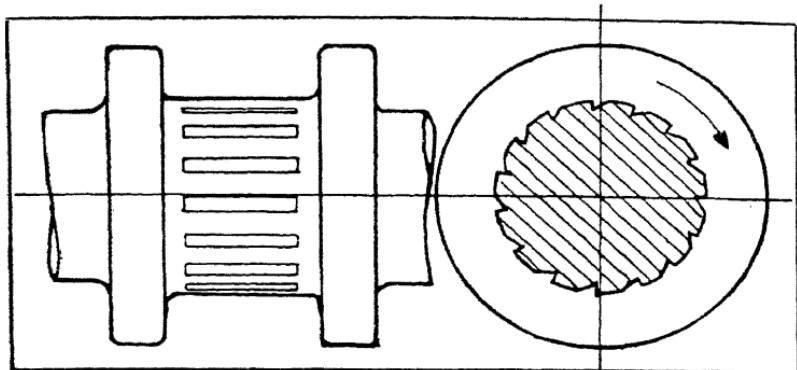


Fig. 56—Indentations of a Set of Blooming Mill Rolls. The Depth of the Cavities Should Be Made Shallow

straight. This is not the case with too small a draft, for the slightest irregularities on the surface of the rolls will have an effect. The minimum draft should be 5 per cent of the height before the pass and not larger than 0.02-inch with thin and 0.04-inch with stock thicker than 0.4-inch.

With excessive draft, the rolls will no longer grip. The gripping properties decrease, as is shown in Fig. 55, with decreasing roll diameter. With the same height and reduction of the stock, the smaller the roll, the larger will be the angle of grip (α is greater than α') and the smaller the tangential component T of the force P , with which the stock is pushed or pulled into

the rolls. On the contrary the radial component R , which goes through the roll axes, and therefore has no drawing-in effect, increases with the angle of grip.

Gripping is dependent on the roughness of the rolls. In the breaking down passes, it is increased by notches or indentations. It is advisable to design the passes so that the rolls will still grip if their surface is not roughened. Indentations will assure gripping, even with turned rolls. The indentations of a set of rolls should be in the shape of broad notches as shown in Fig. 56. Because of the stripper guide resting on the roll it is desirable to leave a border on the right and left sides of the pass. The depth of the cavities and notches should be shallow so that the elevations, which they cause on the stock, can be rolled away. A depth of 3 to 5 per cent of the thickness is satisfactory.

III

PASS DESIGN AND ARRANGEMENT OF ROLLS

ROLL pass design invites close study. If the pass is overfilled, the steel squeezes out at the open places causing the formation of fins; if the pass is under-filled stock of uneven thickness is produced. Frequently the pass is filled but the material is rendered rough or develops stresses which are not relieved. Defective stock may be produced if it is not gripped by the rolls or if it attempts to push beyond or knock out the stripper guides and wrap around the roll forming a collar. If the stock does not leave the roll perpendicular to the plane of the rolls, but at an angle to the side, or if it becomes twisted about the axis, the product will be defective.

The pass, if overfilled, can be made broader or the previous one narrower to allow more spread. Another means of correcting overfilling is to round or bevel off that part of the roll which causes the fin formation. This is an important means for correcting new passes, without excessive machining. Taking out the fillets or bevels, e , of a pass in Fig. 57 can be done on a lathe, without making any changes on the other roll. On the contrary, an increase or decrease of the pass width can only be made to a limited extent and then only by turning down the entire roll. If the lower roll is turned as shown by the dotted line in Fig. 57, a gapping hole at o results, because the part of the upper roll fitting into this is too narrow. To compensate for this opening the roll must be turned down so that, due to the conicity, the desired width b_2 also is restored in the up-

per roll. Since the overdraft cannot be changed the lower roll must be turned down the same amount.

With new difficult passes, the draft and spread are chosen purposely so that without fillets in the roughing pass, the particular shape will presumably be too full. Then a fillet or bevel, which is so large that the shape will apparently be somewhat too empty, is chosen. After putting in the rolls for testing an exact filling can be

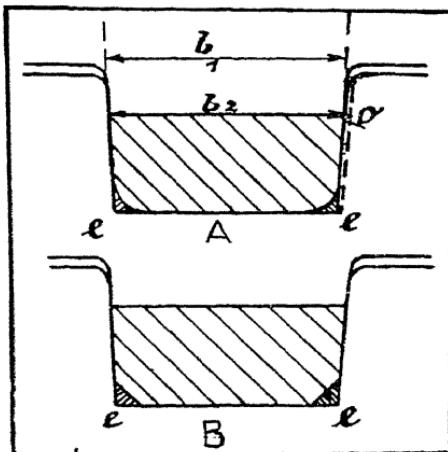


Fig. 57.—Effect of Fillets and Bevels in Correcting New Passes

accomplished by taking off as much of the fillet of the roughing pass as there is steel missing. In addition the fillet centralizes the stock in entering it into the rolls. Where the stock is spread, the profile will be too full on one side and too empty on the other, which cannot be avoided by changes in the width. This is due either to the roll axes not being exactly parallel, or to the diameters at different points in the pass not being equal mathematically. Thus the rolls draw in the stock and press it against one side of the pass.

Finally the formation of the fin can be avoided in that more draft is given in the center of the pass, whereas, the outer parfs shrink and lose the tendency

to go beyond the pass boundaries. The underfilling may be due to the pass as a whole having too little draft or to the distribution of the draft being uneven. In the latter case unequal elongation usually occurs in the individual parts of the cross section and results in shrinkage. Finally the pass cannot fill, because the working diameters are uneven and, therefore, the velocities with which the individual parts of the cross section would leave the rolls, if they were not connected.

How Gripping Is Promoted

The means for preventing the rolls from not gripping are lessening the draft, ragging the rolls and eventually increasing the roll diameter. If the stock does not free itself easily from the rolls, it is due either to a strong pressure against the pass walls necessitating an increased pass spread; or the pass does not have enough taper. Leaving the rolls in a bent condition is due to unequal draft or unequal temperature of the different parts of the cross section. If the former cannot be corrected by changing the roughing pass, the crooked exit must be considered.

Turning in the pass occurs mostly with rounds. With hollow sections the turning can be opposed by a strong guide pressure on the edges. A strong tendency to turn sometimes originates from the roll axes not being parallel due to faulty machining or unequally worn bearings. If center of necks on both sides of roll are not in the depression, the bearings should be changed.

To receive an accurate finished product in the last pass, it is necessary to have a slight draft and an equal reduction over all parts of the cross section. Roll pass designing ends with the shaping of the passes, but the arrangement on the roll is a secondary problem.

Changes in the crystal size can be accomplished in hot rolling by overheating the material, that is, by holding it for a considerable time at high temperatures; and, by recrystallization as a result of deformation at certain temperatures and degrees of deformation.

Hanemann and Hinzmann* determined with a 0.12 per cent carbon steel an abrupt drop of the notch toughness at a crystal size of more than $4500\mu^2$. This crystal size we will call the "critical" and the limits, between which it is obtained at a certain temperature, the "critical deformation." While Hanemann and Lucke** have set up space diagrams for recrystallization on forging soft iron, W. Tafel, H. Hanemann and A. Schneider*** have carried out the same investigation for hot rolling. The space diagram for the latter for temperatures of 680 to 1200 degrees Cent. are shown in Fig. 58. It shows in detail, several deviations from the recrystallization curves set up by Hanemann and Lucke for forging probably as a result of the different stresses, which are relieved by forging and rolling. In principle they show the same trend, that is, the crystal size with slight deformation remains the same or in rolling even becomes somewhat finer (between 900 and 1100 degrees Cent.), then increases abruptly. The degree of deformation, at the lower sudden increase in crystal size, Hanemann called "swell-value." With heavier reductions it decreases gradually, in a hyperbolic course, to the starting size.

In the space curve Fig. 58 is shown the grain enlargement in soft iron at various rolling temperatures and drafts. Roughly it is between 750 and 850 degrees Cent. and 15 to 30 per cent draft. Above 900 to below 1100 degrees Cent. the critical grain size is not attained at any draft; at 1100 degrees Cent. a draft of about 5 per cent is critical; and, at 1200 degrees Cent. the grain size exceeds $4500\mu^2$ at all drafts. In this case the deformation and the overheating seem to work together causing a large grain.

The investigation of recrystallization has given an explanation for the long known phenomena, that in rolling namely in the last pass (there the tempera-

*Stahl und Eisen, 1927, page 1651.

**Stahl und Eisen, 1925, page 1117.

***Stahl und Eisen, 1929, page 5.

ture most easily falls within the danger zone between 700 and 900 degrees Cent.) a coarse grain sometimes suddenly appears. The previously mentioned space diagrams make it possible to avoid this danger and thereby a deterioration of the material by recrystallization.

The first procedure in roll design is to make the hot size 0.13-inch larger than the finished or hot profile. From this is drawn backwards the shaping passes until a profile found either on a billet or a blooming mill is

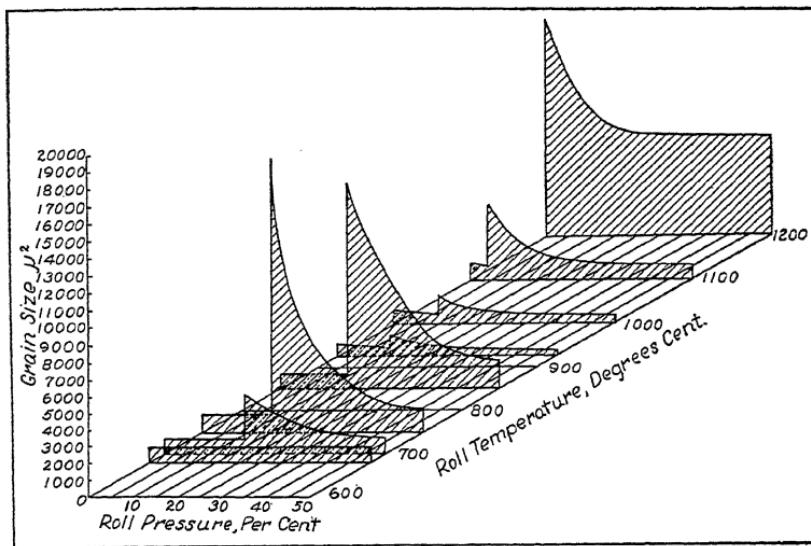


Fig. 58—Space Diagram Showing Recrystallization of Soft Iron After Leaving the Warm Rolls

developed. This actual template or pass drawing shows only the outline of the pass. With rectangular, square and round shapes the drawing can be replaced by tables.

The design is scratched on a steel or zinc sheet with a steel scribe. The sheet 0.04-inch thick then is trimmed along the lines and cut out slightly oversize. The excess material then is filed off, so that the template matches the pass drawing: where possible the checking should be done with the caliper square. With

difficult designs a difference of 0.004-inch may cause trouble. All fillets should be exact. The templates are

Layout of a Pass

Item		
A. Largest shape: channel	.....	5.512"
B. Largest flat or hoop	.....	5.906"
Smallest thickness	.....	0.197"
Smallest width	.....	2.362"
C. Largest square	.....	3.543"
Smallest square	.....	1.575"
Number of passes in item A	.....	9
Average width	.....	5.815"
Inner collar	.....	5.906"
Outer collar	.....	7.874"
Number of passes in item B	.....	6
Average width, largest profile	.....	5.709"
Average width, smallest profile	.....	2.165"
Inner collar	.....	1.969"
Outer collar	.....	2.362"
Number of passes in item C	.....	17
Average size of pass	.....	2.559"
Diagonal of this	.....	3.622"
Inner collar	.....	0.787"
Outer collar	.....	2.362"

TO DETERMINE BODY LENGTH AND DIAMETER

Roll Diameter:

For largest height of the 5.512" channel pass the height, h , equals or approaches 2.362".

The diagonal of the 3.543" square is 5.118".

The height, h , equals 2.559". For rod rolls the diameter is estimated at $10 \times h$ or 25.591".

Body Length:

For channel—	Inches
9 passes of 5.315" av. width	47.835
8 inner collars 5.906" av. width	47.248
2 outer collars 7.874" av. width	15.748

110.831

This length is too long. The body length for shapes should not exceed $3 \times D$, in this case not more than 82.677".

For flats and hoops—

If a large and small profile are placed on each roll the average width is $5.709" + 2.165" \div 2$ or 3.937", and

	Inches
12 passes at 3.937"	47.244
11 inner collars at 1.969"	21.659
2 outer collars at 2.362"	4.724

73.627

For squares—

	Inches
17 passes at 3.622" av. width	61.574
16 inner collars at 0.787"	12.592
2 outer collars at 2.362"	4.724

78.890

used by the roll turner and by the superintendent as a means of control. For this purpose the two mated rolls are set up in the lathe above one another and are pushed together according to the cut-in passes, until the collars are a distance apart equal to the spring. The space remaining empty must then be exactly filled by the template, if the rolls have been turned properly.

Before making the lathe tools the templates with the roll drawing are returned to the office to the roll designer, who satisfies himself as to their checking. They are filed for use in case it is desired to restore the original shape. The templates serve to finish the roll drawing, in that the roll lines first are drawn and the passes with their neutral lines to coincide. Then the collars are drawn free hand in preliminary and if the layout appears satisfactory the templates are traced in with pencil or pen, and the collars drawn in final. Widths and diameters are put in. The drawing made in this manner is shown in Fig. 38. In the roll drawing only the dimensions should be given. If tests show that changes in the rolls are necessary, they should be made from the pass drawing, templates and roll drawing. The practice of the roll superintendent or the roll turner changing the template or the roll directly is objectionable.

Roll design with prospective trains proceeds somewhat differently than with existing trains. In this case, the rolling program first is authorized and an estimated layout of the number of passes and pass widths is made according to the example presented in the accompanying table. A diameter of 25.591 inches and a body length of from 74.803 to 78.740 inches is chosen to provide a full set of square and two sets of flat passes on each roll. If the smaller body length is chosen, the square set will have to be arranged somewhat differently to save this 3.937 inches. The last passes of two or three channel profiles are placed on a finishing roll, and the first on a roughing roll, since the

nine passes would be too much for one roll, and not enough for two.

Ordinarily with new roll trains the entire rolling program is not clearly defined, and, in the course of time, new profiles are added. In spite of this it is not good practice to arbitrarily fix the roll dimensions without considering the profiles to be placed on the rolls. The roll must adjust itself to the rolling program; with stragglers, the roll pass design must adjust itself to the roll.

The last work for roll pass designs, for which new guides are necessary, is to prepare drawings of the guides so that they will be finished at the same time as the rolls. The necessary stripper guards are finished at the same time. The exact fitting to the rolls by machining and filing, is accomplished after the rolls are finished. Test pieces are put through the consecutive passes after the rolls are set so that the thickness of the profile corresponds exactly to the templates or pass drawing, which the roll designer takes for the test. From each pass a piece is cut off and after cooling, sawed or milled so that the profile can be inspected. If the design is correct, the template will cover the profile. If the passes do not fill or if they run light changes must be made in the rolls.

Choice of Rolls

Rolls of pure gray iron, poured in sand, seldom are used for finishing because they are too soft and spall off at the collars too easily. For rods and shapes, the so-called half-hard roll is the best. It contains according to the desired depth of hardness a greater or lesser addition of white iron which is poured into iron molds coated with loam. It receives a slight quenching which renders the surface more or less hard, according to the amount of iron added and the thinness of the loam wash.

Chilled or polishing rolls are necessary, when the stock should have a flat and bright surface, or where

the wear of the groove should be small. The chilled rolls for hoop and sheet steel usually are ground dry.

In case of necessity a useful method for highly-stressed small profiles is to pour a chilled roll and then turn off the outer hardest layer. Beneath is a semihard layer, which in pouring was compressed by the outer layer and made entirely dense. This makes excellent, but expensive rolls. For cogging and bloom-

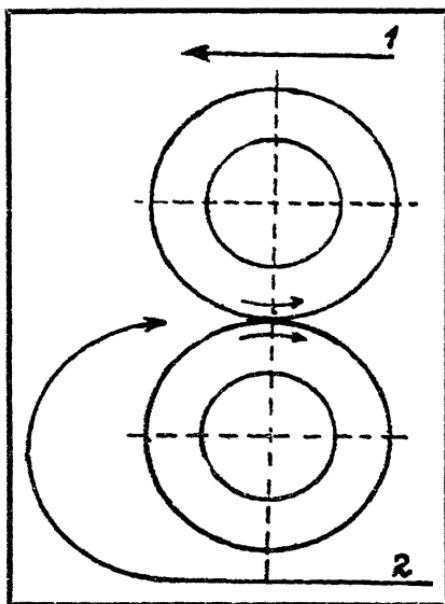


Fig. 59—Arrangement of the Rolls in a 2-High Mill

ing mills, where a flat surface is not necessary the rolls usually are of forged cast-steel. With rolls that are too hard the passes wear out rapidly by burning; in addition they show a tendency toward fire cracks because of the uneven heating of the individual places, which due to the low plasticity of hardened material find little opportunity for equalization.

About 50 years ago old mills were equipped with 2-high rolls. The stock was entered on the one side of

the rolls and had to be returned from the rear to the front side of the mill after the passage. This was done either by pulling it over the upper roll as shown by direction 1 in Fig. 59; or it was passed beneath the lower roll, bent upwards with the tongs and again entered between the two rolls as shown by direction 2. To give the stock an edging pass in the first method,

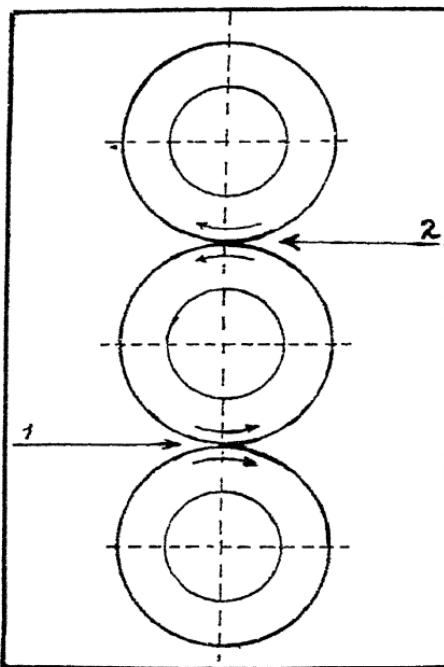


Fig. 60—Arrangement of the Rolls in a 3-High Mill

requires a knack on the part of the crew especially with long bars. With the second method as shown in Fig. 59, the side, which previously was up, is down after the bending during the second pass. The bending, however, is only possible with thin stock. Ordinarily the 2-high rolls in this form are no longer used.

To obtain a larger output a third roll was installed. The stock is entered as shown in Fig. 60, for example,

between the lower and the middle roll, and is returned to the same side between the upper and the middle roll. By this arrangement in comparison with the ordinary 2-high mill the output is doubled in less time.

The advantage of the 3-high mill, namely that the return takes place with the same expenditure of roll work, is possible with the 2-high mill, if two sets of rolls are arranged side by side or in front and above one another. The first arrangement is called alternating 2-high and finds use in all cases, in which the stock is thin and does not drag on the floor for any great distance between passes. In the 3-high mill the ends of the stock only touch the floor every second pass, as they are caught by the roller with tongs and immediately entered again. Meanwhile, the stock lies on the floor between each pass, and does not cool uniformly. The alternating 2-high mill is desired, where long rods are rolled, as with wire, small hoop steel, etc. The set-up as shown in Fig. 61 is somewhat as follows, that is, in one stand of a 3-high housing a roll is placed at the bottom and in the middle, and a so-called driving spindle is mounted above. In the adjacent stand a roll is placed above and in the middle. The former top roll of the second stand is coupled with the driving spindle of the first stand. At the bottom of the second stand the spindle, in place of the roll, transmits the power to the lower roll of the next stand.

Different Effect Is Obtained

If instead of placing the two 2-high stands adjacent they are placed in the same housing in such a way, that their two roll planes are in front of one another and the bottom roll of the one set lies somewhat higher than the top roll of the second as shown in Fig. 62, the so-called double 2-high effect is obtained. The driving spindles are unnecessary in this case, because in the one roll plane the adjustment is made only from above, and in the other from below. On the contrary this makes for a complicated transmission, because of the

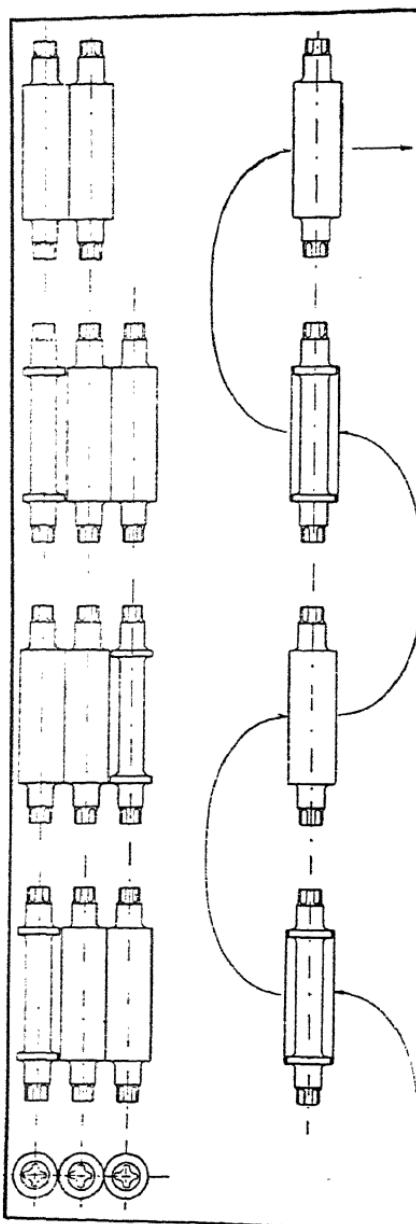


Fig. 61—Arrangement of Rolls in an Alternating 2-High Mill. The Finishing Rolls of Such Trains Usually Are Adjusted from Above

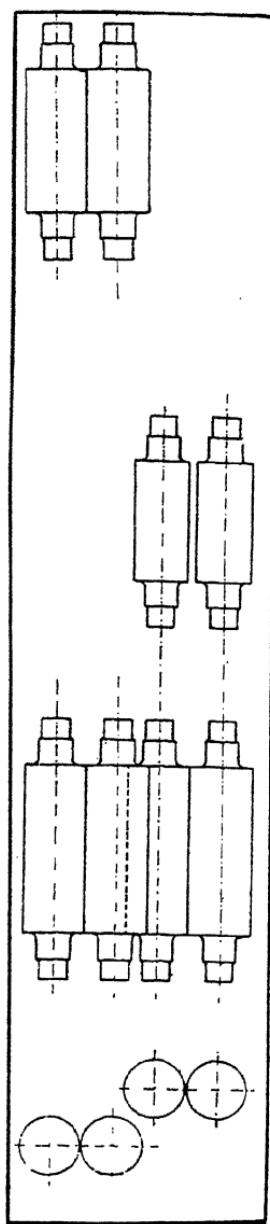


Fig. 62—By Placing Two 2-High Sets of Rolls in the Same Housing, So That Their Two Roll Planes Are in Front of One Another and the Bottom Roll of One Set Lies Higher Than the Top Roll of the Second, the Double 2-High Effect Is Obtained

two pairs of gears and the connection between the two with a fifth gear. This type is known as Dowlar's mill.

The 2-high mill still is used to advantage today, namely in the reversing mill, that is, a pair of rolls which can be run in one direction and then the other by reversing the driving medium. The advantage of this type is, that during the rolling pauses the train stands still. In addition the stock always remains in the same horizontal plane and need not be lifted or lowered by tilting tables or similar devices, as is the case with the 3-high mill. Installation costs for the mill and housings also are lower. The principal advantage is, that due to dispensing with the flywheel, which cannot be used in a reversing mill because the reversing could then only take place after considerable retarding work, the number of revolutions can be varied to suit conditions.

Involves Some Objectionable Features

Disadvantages of the reversing mill include the accelerating work which is used, the impact which occurs in reversing due to the play in the couplings in the mill and the driving motor. An additional disadvantage is that the material, due to the bevel, requires turning through 180 degrees after every pass, unless in the first pass the lower roll is given the positive collars and the upper roll the negative collars or vice versa in the next pass as shown in Fig. 63. The arrangement of the roll collars avoids turning, but requires much room on the roll.

The reversing engine must develop the maximum amount of rolling energy because the flywheel is dispensed with. It frequently is of larger dimension than a machine with which the peak loads are absorbed by the flywheel and, therefore, costs more. With electric power, transformers must be added, which makes the cost of reversible motors much higher than ordinary motors. The steam engine, if it is reversible, has a higher steam consumption per horsepower hour than

one equipped with a flywheel. With the 3-high mill without turning the stock a change of sides takes place, on which the bevel, that is the opening of the pass, lies. This omission of the turning is the principal reason why 3-high mills work so rapidly.

An advantage, which the reversing mill and the

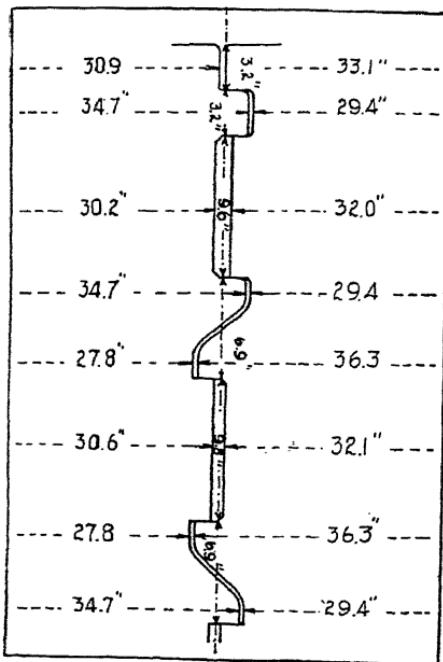


Fig. 63—Arrangement of Positive and Negative Roll Collars

double 2-high, but not the alternating 2-high and the simple 2-high share with the 3-high is the change of the rolling direction. With alternating and simple 2-high mills the same end of the stock always is served to the rolls first, while with the 3-high unit the ends alternate. With cross sections having equal draft in all parts a certain flowing apparently takes place between the inner and outer parts. This relieves the stress in part, due to the different elongations; although as much stress re-

mains as is necessary to induce flowing. The residual stress is removed by every second pass if the rolling direction changes, while it increases with every pass, if this is not the case.

The disadvantages of the 3-high mills are:

1. The mechanical adjustment is more difficult than with the 2-high.
2. The set up of the rolls and the regulation of the guides require twice the time than with a 2-high mill of the same diameter.

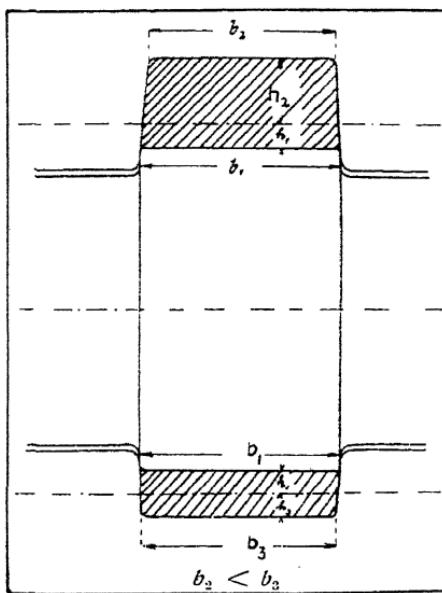


Fig. 64—Different Pass Depths Are Required for Different Widths

3. In the side adjustment, the rolls of the 3-high mill are dependent on one another. If the middle roll is moved in relation to the top, to make corrections, the bottom roll no longer will match the former but also must be corrected.

4. With the 3-high mill either above or below every used pass there is a so-called blind opening. Or with a pass which lies immediately below or above the blind pass the layout is bound to the width of the latter. Therefore, the spread is limited. This results from the taper if the previous pass is cut considerably deeper into the roll as shown in Fig. 64.

5. The sources of error, that is the spring in the bearings in the vertical as well as in the lateral direction and other differences, are larger with the 3-high than with the 2-high mill. The rolling will be less accurate than with the 2-high unit.

6. As previously mentioned, it is desirable to make the lower

roll grooved and to provide the upper roll with overdraft. This is impossible with the 3-high mill. If this condition is fulfilled between the middle and the upper roll, it cannot be fulfilled between the middle and the lower roll.

The errors under items 3 to 6 are avoided with the double 2-high. The disadvantages of this construction are that long stripper guards are necessary with the lower set of rolls, because they must be carried under the upper set; and, that the driving in the two roll planes gives a complicated arrangement of the drive pinions, which is bound up with the higher use of power. Finally the lower and upper planes, in which the bending is done, lie further apart than with the 3-high. It is therefore not to be advised for roll diameters, over 15.748 to 17.717 inches. A good solution is to combine the 3-high and the 2-high in a way, that the finished pass and the last shaping pass will be on one or two 2-high mills, the rest of the roughing passes on one or more mills of the 3-high type.

The finishing rolls on small trains, of about 21.654-inches diameter are mostly adjusted above as shown in Fig. 61. With large trains, the adjustment is made from below, so that the last pass will leave in the height of the cooling beds.

Train Handles Various Shapes

This arrangement is adapted to the rolling of flats with the roughing passes on a 3-high and an ending and polishing pass each on one 2-high mill, as well as to the rolling of guide rounds with the roughing passes on a 3-high mill and an oval and finishing pass each on one 2-high mill.

The train also is adapted to the rolling of other profiles such as large squares, roughing on the 3-high with one finishing pass on the 2-high; for angles or tees, which should not have exact thickness in the legs; and, for rods 15.748 inches diameter or less. With this arrangement the advantages of the 3-high and 2-high mills are combined using the roughing passes with which 0.004-inch makes no difference with the speed and change

of rolling direction, while the finishing pass offers exactness, which only the 2-high permits.

The 3-high is made by placing a third roll either above or below the ordinary 2-high, whose lower roll is grooved and the upper roll tongued. In the first case the grooved roll is above and below, in the second as shown in Fig. 65, *a* and *b*. In Fig. 65 the added roll is

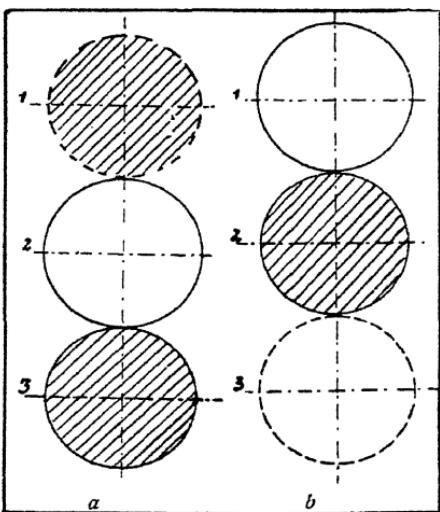


Fig. 65—Different Methods of Origination for a 3-High Mill

of larger diameter than in *b* of smaller diameter than the middle roll, with overdraft above (between 1 and 2) and below (between 2 and 3) as desirable. But the condition, that the overdraft be with the tongued roll, which was determined previously, so that the sticking and the overdraft both act in the same direction, is only satisfied between 2 and 3 with *a* and between 1 and 2 with *b*.

In addition these arrangements have the disadvantage, that the upper and lower rolls are not equal, therefore, cannot be interchanged. This is necessary though, where dead holes exist and where use is to be made of them. If we interchange the top and the bottom roll,

without further consideration the used passes become dead holes and vice versa. If the top and bottom roll are of the same diameter to make them interchangeable as shown in Fig. 65 underdraft exists in Fig. *a* between 1 and 2, in Fig. *b* between 2 and 3. In this case the stock must be prevented from climbing by a hanging stripper guard which is pressed against the upper roll by a counterweight or a spiral spring and must also be placed where there is underdraft, and where the

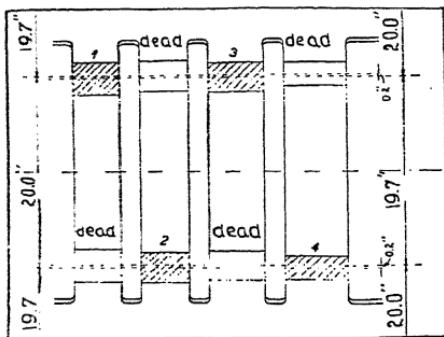


Fig. 66—Method of Changing Overdraft and Underdraft from Pass to Pass

grooved roll lies above, that is in case *a* at 1, in case *b* at 2.

Such hanging guides are undesirable, because they hinder the oversight and accessibility to the rolls and cause disturbances, if the piece should go through the guides sidewise.

A third possibility of interchanging the upper and lower roll exists. The rolls are given two diameters. In fact the upper roll in comparison with the middle is given a larger diameter, where the stock is entered above, and a smaller where it is entered below. Overdraft exists in the used passes between the top and middle roll as well as between the middle and the bottom rolls, and still the top and bottom rolls can be interchanged. The latter will only wear half as fast, as the

middle roll, with which all passes are being used continuously. An allowance for this is had by finishing two middle rolls and setting the second in as soon as the top and bottom rolls are interchanged.

Usually only grooved rolls are considered undesirable to set the passes so far apart. The overdraft in the rolls can be changed in any pass as desired. For this purpose as shown in Fig. 66, two average roll diameters are assumed, one so that the top roll is larger than the middle, and one so that the opposite is true. In the first roll line the middle lines of those passes which are to be entered above are placed and in the latter, those which are to be entered below. If the middle roll is taken as the tongued and is given large overdraft, the hanging guides can be omitted. The method of two average diameters can be considered as the best for 3-high construction.

The disadvantage is that the center roll, in which all passes are always in use, becomes worn more than the upper and lower roll, with which half the passes are always "dead" passes. This can be remedied by making and inserting a duplicate center roll when interchanging the top and bottom units (four roll system). The various passes in the three rolls then are used equally. As a result the wear will be equal.

IV

MERCHANT BARS

RECTANGULAR profiles are named according to their method of manufacture, size and shape, and use. Universal steel is a flat section, about 3.937 inches to 23.622 inches in width and rolled on the universal mill.

Hoop steel has a rectangular cross section and its thickness is small compared to its width. The product is used as bands for boxes, fences, barrels, etc., and generally is bundled although it frequently is delivered in coils like wire. Dimensions range from 0.394 x 0.035-inch to 5.906 x 0.236-inch. Steel for the manufacture of welded pipe from about 1.181 x 0.059-inch up to all rollable widths but cut into strips to the length of the pipe to be made, is known commercially as skelp.

All other rectangular cross sections, except the periodic, are designated flats. Dimensions of this section range from 0.394 x 0.113-inch to about 7.087 x 2.362-inch. They should be considered as basic for all irregular profiles. Flats generally are rolled on a 3-high mill or on a double 2-high mill. Thin and narrow flats frequently are rolled on the alternating 2-high mill to prevent cooling. The roughing passes before the edging and polishing rolls can be executed either on a flat roll or in closed passes. To produce the different thicknesses in the first case an offset roll body as shown in Fig. 67, frequently is used. The method of rolling is called step rolling of flats. The advantage of stepped rolls is that the whole rolling program of a train can be covered by one stand.

The size of the square billet necessary for a desired flat is determined from the drafts and the spreads. If the billets are rolled on the flat sides several times in succession, the edges become rounded. An edging pass, therefore, must be inserted after the stepped roll, through which the stock passes with its edges upward. The steel must be pressed stronger in this pass, the oftener it is passed through on the flat sides, in order to

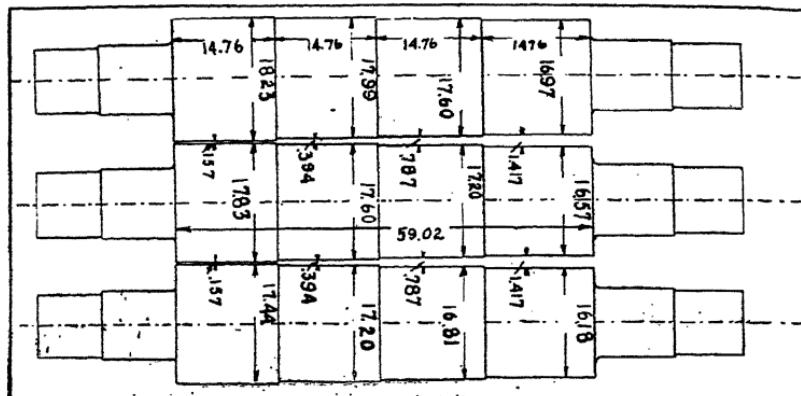


Fig. 67—Offset Roll Body for Producing Different Thicknesses of Flats. Dimensions Are Given in Inches

restore the perpendicular sides which were destroyed.

As mentioned in Chapter I a draft from 5 to 10 per cent, but at least 0.02-inch is used in the last pass, so that the piece will leave the rolls straight. In the first passes at white heat, 50 per cent should not be exceeded on account of the gripping, and if the billet is at a red heat, not over 35 to 40 per cent. The flat drafts are determined between these limits. The edging drafts with thin sections are chosen from 5 to 15 per cent, so that the rod will not buckle or fold.

The dimensions for obtaining a flat rod can be determined accordingly. Suppose the finished profile is to be 1.181x0.394-inch. The hot profile may be disregarded in this case, because a small correction can be

made in setting the rolls correctly in the housings.

The draft in the polishing roll is about 10 per cent or 0.039-inch; the spread from this is 0.35×0.39 or 0.013-inch. The rod must be 1.167 inches wide and 0.434-inch thick when it leaves the edging rolls in order to measure 1.181x0.394-inch after passing through the polishing roll. The draft in the edging rolls also amounts to 10 per cent or 0.118-inch. The spread when edging is insignificant and can be amended by a small correction in the finishing rolls. The rod, therefore, enters the edging roll, having left the last pass on the stepped roll with a size of 1.28 x 0.433-inch. In this pass 30 per cent draft should be given; the rod must enter the last pass on the stepped roll with a thickness of $0.433 \div 0.7 =$ or approaches 0.618-inch. The spread with this warm pass is about 0.25 times the draft, or approximately 0.039-inch, with a width of 1.245 inches. The stepped roll must be set accordingly. In determining whether a square can be brought to this cross section with one pass, supposing one with a side of 1.181 inches be taken. The draft would be $1.181 - 0.614 = 0.567$ -inch and the reduction $(0.567 \div 1.181) \times 100 = 48$ per cent. It would be better to choose the draft in the last pass on the stepped roll somewhat larger than 30 per cent to cut down the first draft; or, to make three instead of two passes on the stepped roll. Dimensions, therefore, would be:

Pass	Thickness, inch	Spread, inch	Width, inches
Third stepped	0.433	.....	1.299
Second stepped	$\frac{0.433}{0.75} = 0.573$	0.039	1.260
First stepped	$\frac{0.573}{0.65} = 0.866$	0.079	1.220

A square 1.122 inches would have a draft of 0.256-inch and a spread of 0.059-inch would be satisfactory. With broader surfaces more flat passes are necessary. If the desired square is not on roughing rolls, the next highest is taken for reduction on the stepped rolls.

Stepped rolling only is advised for flats, up to about

2.362 inches wide. With broader sections, so many flat passes are necessary, that a heavy edging draft would be necessary to press away the bulging out at the side. Thus, the broad flat will not stand when turned on edge, in fact it has a tendency to fold. Flats over 2.362 inches wide are rolled more advantageously in closed passes which also are recommended where small quantities of one kind, particularly of one thickness are to be made. To change the thickness without changing the width is easier in the pass than with step rolling.

Closed Passes Promote Accuracy

Accurate rolling above all sharp corners with broad profiles requires closed passes. Where no edging roll is available, the sizes must be arranged like the rolling program. Only 0.039-inch in width can be equalized by the larger or smaller draft in the polishing rolls. Therefore, if the rolling program includes the sizes 1.732, 1.772, 1.1811, etc. up to 2.362, then 2.559, 2.575, 2.954 inches, etc. up, the roughing passes up to 2.362 inches must increase in steps of 0.079-inch, from there on in steps of 0.197-inch.

If the steel is edged before the polishing pass, the increments in width can be taken larger, and according to the following consideration: The edging draft must be at least 0.197-inch and should not be more than 15 per cent. A flat of 4.724 x 0.394-inch, therefore, must be edged at least 0.236-inch and not more than 0.709-inch. The edging rolls can cover a difference in width of 0.472-inch. The steps chosen in the roughing pass should vary by 0.394-inch or 4.724, 4.764, 4.803 inches, etc.

A stepping in the thickness of flats is necessary only with wide limits because the different thicknesses are reached in the same passes by raising or lowering the rolls. A different setting of the rolls, as explained in Chapter I, changes the percentage of the draft. The lowest position of the finishing pass of a flat 3.937 inches

wide, for example, shows the thickness equal to 0.394-inch. The roughing pass has a height of 0.512-inch. Reduction of the former is therefore $(0.118 \div 0.512) \times 100 = 23$ per cent. The passes should be on a 2-high mill. To arrive at a thickness of 1.181-inch in the finishing pass, the roll must be raised 0.787-inch. The thickness of the roughing pass will therefore be 1.299-inch and the reduction is $(0.118 \div 1.299) \times 100 = 9$ per cent.

With rectangular cross sections distinction must be made between relative and absolute draft. The latter from pass to pass of a whole set is designated as the draft stage. This is a position of the last pass with

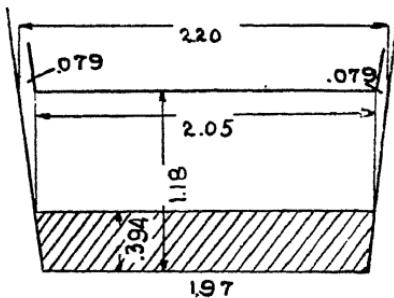


Fig. 68—Large Tapers in Rolls Intended for Rectangular Profiles Result in Wide Roll Gaps. Dimensions in Inches

which the thickness of the rolled flat would become equal to zero. The draft stages therefore always begin with zero. If the actual thicknesses increase from 0.394-inch to 0.512 to 0.709 to 1.024 to 1.693 inches, this is termed a draft stage of zero; 0.118 (derived by subtracting 0.394 from 0.512); 0.315; 0.630; and 1.299 inches.

Rectangular profiles, with which the height in relation to the width is small, have a somewhat smaller spread because of their greater resistance to flow. They, therefore, require a larger taper than the thick profiles because they are subjected to higher pressure, and wedge

Draft Stages and Fillets for Flats

(Fillet approximately equals $(0.3 \text{ to } 0.5)d$ in the next to last and $0.5d$ in previous passes.)

Dimensions, Inches	Pass Height with Zero Setting of the Finishing Pass	Fillet Radius, Left Last—Right First Pass	Fillet Radius, Left Last—Right First Pass	Taper in %
(0.394 to 0.784) \times 0.157 and Heavier.....	0 0.0787 0.236	0 0.0276 0.0787	0 0.0276 0.0787	0.118 0.157 0.197
(1.024 to 1.181) \times 0.157 and Heavier.....	0 0.098 0.315	0 0.039 0.118	0 0.039 0.118	0.118 0.157 0.197
(1.260 to 1.811) \times (0.157 to 0.315).....	0 0.098 0.315 0.907	0 0.039 0.118 0.197	0 0.039 0.118 0.197	0.138 0.157 0.197 0.197
(1.260 to 1.811) \times 0.354 and Heavier.....	0 0.118 0.472	0 0.039 0.177	0 0.039 0.177	0.118 0.157 0.197
(1.890 to 2.244) \times 0.157 and Heavier.....	0 0.118 0.334 0.787	0 0.039 0.118 0.197	0 0.039 0.118 0.197	0.118 0.157 0.197 0.197
(2.283 to 3.150) \times (0.157 to 0.315).....	0 0.098 0.315 0.728 1.457	0 0.039 0.118 0.197 0.394	0 0.039 0.118 0.197 0.394	0.138 0.157 0.197 0.197 0.197
(2.283 to 3.150) \times 0.354 and Heavier.....	0 0.138 0.472 1.181	0 0.049 0.177 0.354	0 0.049 0.177 0.354	0.118 0.157 0.197 0.197
(3.228 to 4.724) \times 0.354 and Heavier.....	0 0.118 0.433 0.984 1.890	0 0.059 0.157 0.276 0.194	0 0.059 0.157 0.276 0.194	0.118 0.157 0.197 0.197 0.197
(4.803 to 7.284) \times 0.354 and Heavier.....	0 0.157 0.472 0.906 1.772 3.150	0 0.079 0.157 0.197 0.354 0.472	0 0.079 0.157 0.197 0.354 0.472	0.118 0.157 0.197 0.197 0.197

themselves in easier. If this larger taper were retained the profiles would have large openings in the higher position. An example of this is given in Fig. 68, with a taper of 10 per cent and a thickness of 1.181 inches. The opening equals 2.205—2.048 or 0.157-inch, if the rolls close exactly at 0.394-inch. Such openings result in unbecoming edges. Special rolls, therefore, should be used for light and heavy sections. Hoop steel especially should not be rolled on rolls designed for flats.

In Table II, recommended draft stages are given in

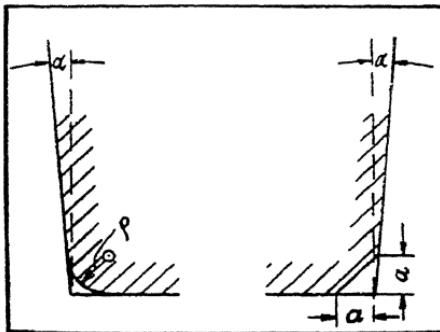


Fig. 69—Fillet and Bevel of a Roll Pass

column 2, the taper $\tan \alpha$ in column 4 and in column 3 the fillet or bevel of the particular pass such as α and p in Fig. 69. Such draft stages, on which the roll designer can enlarge and refine from his own experience for the different roll diameters and kinds of material, can be determined by means of Geuze's formula for spread. With this the roll design of flats is finished. In the lowest position of the rolls the allowable maximum draft measured in per cent should never exceed 50 per cent for the first white hot passes and $33 \frac{1}{3}$ per cent for the later passes. Likewise with the highest position of the rolls, the necessary lowest draft should be from 5 to 10 per cent. This usually is less for heavy profiles and more for light profiles. Where this is not the case, the draft stage must be corrected accordingly.

If with the highest position of the rolls the square cross section is approached, so that the entering billet or ingot receives less than 33 1/3 per cent draft, that particular pass is omitted and it is entered into the second, third, etc., pass. To omit the last passes instead of raising the rolls and to go from a roughing pass into the polishing rolls, is not permissible, because the last pass cannot have a bevel.

Roll Set-up for Flats

The best method for rolling flats is to have a special closed pass turned into the rolls for every pass calculated in the following example and, in rolling, to set in the draft stage as determined. The setting of the rolls should only be changed when changing to another thickness and in this event with a 3-high mill the top and bottom roll should be changed the same amount and with the double 2-high mill both pairs of rolls the same amount. The best procedure is to start with the largest and go to the smallest section, rolling all widths turned into the particular roll of the same thickness and then set the rolls to the next smallest thickness and so on. In this way only a small number of size changes are involved and the roll designer is assured that the drafts on the mill are actually held. For this purpose it is best to make the draft stages known to the roller and to take tests from the roughing passes. Only in this way is it possible to get the correct flat section without unnecessary trials. If the roller works too much with the calipers there exists the danger, that the product will be judged only by the finishing pass, while in the roughing passes wrong draft and fins or underfilling exist.

Special passes for every draft, however, require much space on the rolls, a large roll storage and frequent roll changes. Rare dimensions often require deviations from this method. The blind passes also are used and, therefore, are possible only after every second pass

Otherwise, the design remains the same as previously outlined.

Order of Passes Important

To use the various passes in a different order to vary the draft is not good practice because of error of inexact roughing passes or lengthy trials. The prerequisite for good working is supervision and a firm adherence to the plans of the roll designer.

In designing a flat pass 3.937 x 0.394-inch to 3.937 x 1.181 inches, the hot profile of the lightest section will be (3.937 x 0.398) x 0.394 approaches 3.996 x 0.394-inch. In the case of the thickness, the roll designer does not consider the contraction in cooling since this can be remedied by lifting the rolls slightly. The hot profile is designed backwards using the draft stages in Table II, column 2, line 8, as shown in Table III.

Increase Is Disregarded

The slight increase in thickness, which the rod experiences in edging, is not considered because it is easily removed in the polishing pass. The last roughing pass must be broader than the rod to be entered into the polishing rolls. In this case it amounts to 10 per cent. The spread is calculated according to Geuze as 0.25 to 0.35 of the draft; but with flats of the customary thickness it is at least 0.0197-inch and at most 0.187-inch. With sufficient conicity and bevel it can be taken somewhat smaller, to get good side work and sharp edges. The steel is edged in every pass about the same amount at the sides.

With the heavier section the first pass can remain unused, because a 4.055-inch square will be gripped by a pass with the height 2.205 inches or 46 per cent of the draft and fill the width of 4.173 inches. The two columns for the draft show that with the lighter section at no time is the permissible amount of 45 to 50 per cent exceeded; with the heavier section the minimum of 10 per cent is reached, except from the fourth to the

Table III
Draft Stages and Dimensions for a Hot Flat Profile

	Draft stage, inches	Smallest dimension, inches	Draft, per cent	Largest dimension, inches per cent	Draft, inches	Fillet, inches	Taper, per cent
Polishing pass .....	.....	3.996 x 0.394	.....	1.18	.....	.....	.....
Edging pass .....	.....	3.976 x 0.433	.....	1.22	.....	.....	3
No. 6 roughing .....	.....	4.370 x 0.433	.....	1.22	.....	.....	.....
No. 4 roughing	0.113	4.331 x 0.551	21.6	1.34	9	0.196	4
No. 3 roughing	0.433	4.292 x 0.866	36	1.65	19	0.167	5
No. 2 roughing	0.984	4.173 x 1.417	39	2.20	25	0.276	5
No. 1 roughing	1.889	3.976 x 2.323	89	.....	.....	0.394	5

fifth roughing pass, where it only amounts to 9 per cent. This small difference can be disregarded, as the heavier section seldom will be rolled. The difference, however, can be corrected by increasing the draft from 0.118 to 0.138-inch, the thickness from 0.551 to 0.571-inch respectively, from 1.339 to 1.359 inches. The draft in the polishing rolls need not be checked, as this is independent of the roughing rolls. If it is too small, the roller need simply pull down a little more on the roughing rolls.

Test Is Essential

The first roughing pass of the lighter section is filled out easily by a square of a 3.937-inch side which is gripped easily by a height of 2.323 inches or 41 per cent. The test, to see if the first pass approaches the square cross section enough to fill it and to be gripped, must always be determined if the number of passes has been chosen correctly. If the drafts are over 40 to 45 per cent according to the size of the roll diameter the rolls must be roughened, to promote gripping.

For the second example, using flats 1.575x0.157-inch it is assumed that the draft stages are not available. The steel should be rolled without edging. The minimum draft should be 0.039-inch and the least spread 0.0197-inch. The hot profile will be $(1.575 \times 1.013) \times 0.157 = 1.595 \times 0.157$. The last roughing pass, therefore, will be 1.575x0.197-inch. On account of the long length the stock will not be hot and, therefore, the largest draft will be about 40 per cent. For the intermediate passes the increased draft will be about 20, 30 and 40 per cent. This gives draft stages of 0.197, 0.246, 0.354 and 0.591-inch and widths of 1.555, 1.535, 1.496 and 1.437 inches.

For a width of 1.437 inches a square of 1.299 inches is necessary. This corresponds to a draft $(0.709 \div 1.299) \times 100$ or 55 per cent which is too high. In order not to require a fifth pass the previous passes are given a draft of 30 to 35 per cent instead of 20 to 30 per cent. This

gives draft stages of 0.197, 0.276, 0.433 and 0.728-inch for a 1.299-inch square which corresponds to a draft of 44 per cent. A draft of this percentage will be satisfactory with good roughing and low rolling temperature. Conicity for the last roughing pass arbitrarily is chosen as 3.5 per cent and for the rest as 5 per cent. Fillet radius or bevel ranges from 0.3 to 0.5 of the draft. If the radius of the fillet is a little too large at the beginning, it can be reduced after a trial setup of the rolls. The first pass is chosen as 0.119, the second as 0.0767 and the third as 0.0197-inch. The widths are determined as in the first example and the following figures for the roll drawing of the roughing rolls apply:

Pass	Width, inches	Thickness, inch	Taper per cent	Fillet, inch
Roughing No. 4.....	1.555	0.197	3.5	.....
Roughing No. 3.....	1.535	0.276	5	0.0197
Roughing No. 2.....	1.496	0.433	5	0.0787
Roughing No. 1.....	1.437	0.728	5	0.1190

The foregoing design was developed for a 2-high mill; Example 1 for a reversing mill and Example 2 for a double 2-high or an alternating 2-high mill. If it should be placed on a 3-high mill the dead passes should not be used. If a 3-high is being considered and it is desired to conserve space on the roll, the passes are put above one another and one spread omitted. In Example 1, therefore, the widths are 4.370, 4.370, 4.252, 4.252 and 4.055 inches. The pass spread from the first into the second pass is here purposely taken 4.055 instead of 3.976 inches as in Example 1. If the widths are referred to the base of the pass, a spread will occur from the fourth to the fifth and from the second to third pass. This is because the previous pass is cut somewhat deeper into the roll while the taper is somewhat narrower at the bottom than the following one as shown in Fig. 64.

The pass drawing can be omitted in the case of rectangular profiles and the roll drawing can be finished directly from the tables as determined in Examples 1 and 2. The rolls can be turned without templates; it

suffices for the roll turner to have templates as shown in Fig. 70 for the different conicities and bevels or fillets. The theoretical widths are referred to the neutral or middle line. As the roll turner cannot determine these, it is advisable to measure the widths at the bottom of the pass where the bevel or fillet begins.

As the stock must always be entered so that the

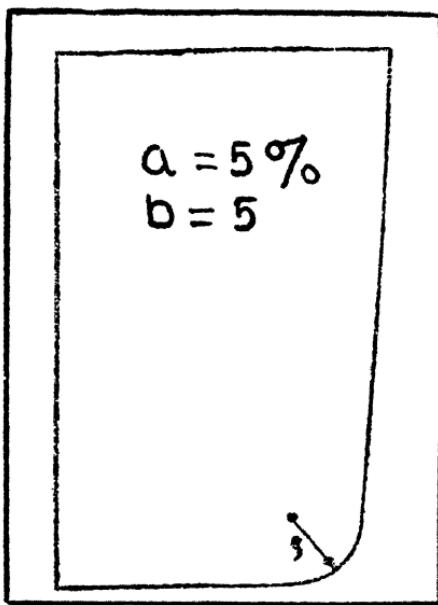


Fig. 70—Template for a Fillet

closed side becomes the open side in the next pass as shown in Fig. 71, the spread in the latter will be smaller and in the former larger than is shown in the tables. This is partly the reason why a lower spread can be used than the values given by Geuze's formula.

Before the roll drawing is started, a division is made and for this purpose the breadth of the outer and the approximate breadth of the inner collars are determined. For the latter the old thumb rule is that the

width of the collar equals the depth of the pass. Where space is scarce, the width can be made about 25 per cent narrower. The outer collars are made one and one-quarter to two times the width of the largest inner collar, so that the housings will not interfere with the guides, the former being applicable with large diameters and the latter with small diameters.

It is assumed that a 2-high mill is to be designed for 3.937-inch flats according to Example 1 as recently presented and for 2.757-inch flats of the same thicknesses. First the pass depths are determined. For the highest position of the rolls according to Fig. 72, it is equivalent to $h+a$. In this formula a is the amount the rolls can be raised and still be interlocked. It ranges

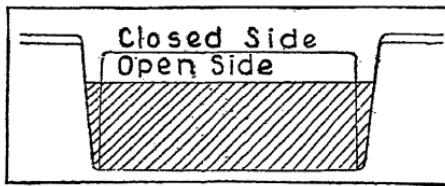


Fig. 71—Spread of the Open and Closed Side of a Pass

from 0.118 to 0.394-inch according to the roll diameter. We will assume it to be 0.236-inch. For the first roughing pass of Example 1 according to column three in the table $h=2.323$ inches. Ordinarily the fifth columns will give the largest pass depth but as that roughing pass is omitted in this case, the first pass with the lightest dimension is deeper than with the heaviest. The pass depth, therefore, is 2.559 inches; for the shallowest or fifth roughing pass $h=1.120$ inches; while the depth is 1.457 inches. The largest inner collar is 2.559 and the smallest 1.457 inches. The average inner collar is $(2.559 + 1.457) \div 2$ or 2.008 inches and the outer 3.937 inches. With the 2.757-inch flat four roughing passes will be satisfactory because the roughing pass 2.992×1.417 will be filled by a 2.835-inch square and will grip if the rolls

are well roughened. The layout, therefore, includes nine passes which require two outer and eight inner collars. The division is somewhat as follows:

Item	Inches
Pass widths for 3.937" including 3.966, 4.173, 4.252, 4.370.....	21.181
Pass widths for 2.757" including 2.992, 3.071, 3.150, 3.189.....	12.412
Two outer collars at 3.937 each	7.874
Eight inner collars at 1.969 each	15.748
Total	57.215

If it is desired to have the body length in round numbers either 55.118 or 59.055 inches is chosen. In the first case the outer collars need only be taken about 1.181 inches narrower, in order to save the 2.087 inches, which makes the layout wider than 5.118 inches. Or 0.197-inch can be saved on each one of the inner col-

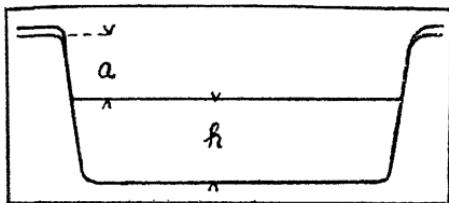


Fig. 72—Interlocking of the Rolls

lars, and the remainder on the outer. In developing the roll drawing outer collars are not drawn until the space remaining between them can be divided. We then have a roll drawing similar to Fig. 73, which for simplicity is drawn as a simple 2-high, probably a reversing mill.

A set of 3-high rolls with dead passes is developed without anything additional, if a third roll with a diameter of 23.228 inches is placed above. In this case the roll drawing in Fig. 73 simply repeats itself. Both lie above one another, but the distance, 23.622 inches, between the axes is not generally made full size. The roll turner does not take the diameters from the drawing but from the dimensions as entered. In the case of the body length the actual size purposely is chosen, so that the roll turner can transfer the widths directly from

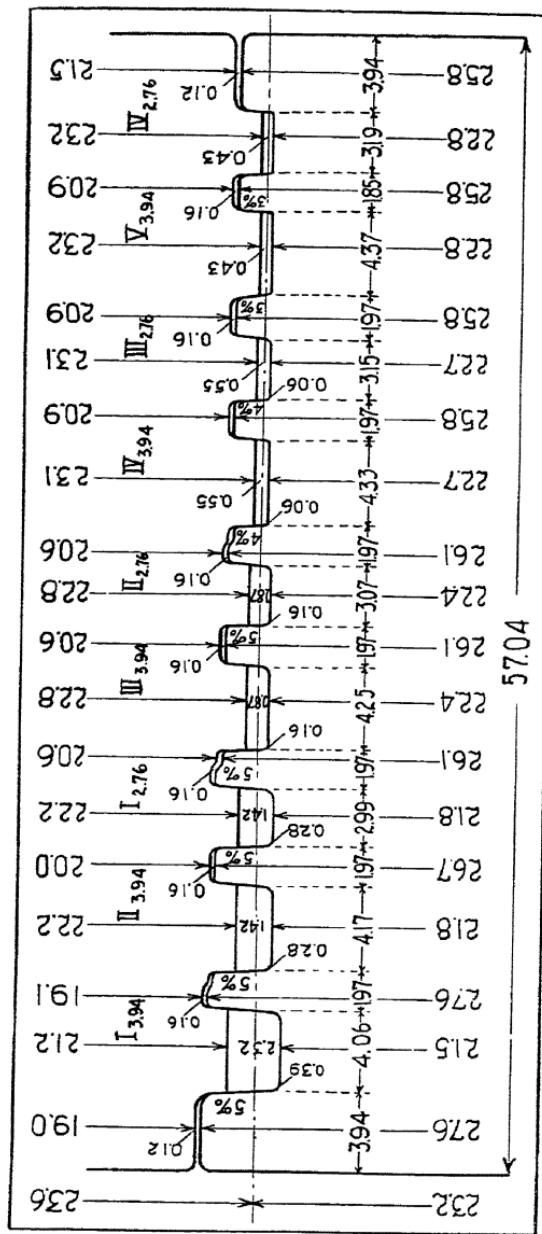


Fig. 73.—Scheme for Developing a Roll Drawing for a Set of 2-High Rolls or for a Reversing Mill.

the drawing, which he tacks on a board and lays on the lathe directly in front of the roll. This can be done by chalking the body and scribing with the steel scribe.

If the dead passes in the 3-high mill are used, twice as many profiles can be rolled, such as 3.937, 3.543, 3.150 and 2.757-inch flats, if the body is lengthened slightly. The division would then be as follows:

Finished shapes	3.937	3.543	3.150	2.757
Pass Nos. 4 and 5	4.370	3.976	3.583	3.189
Pass Nos. 2 and 3	4.252	3.858	3.465	3.071
Pass No. 1	4.055	3.661	3.268	.....
	—	—	—	—
	12.677	11.495	10.316	6.260
Total five passes				40.748
Nine inner collars at 1.969 inches				17.721
Two outer collars at 3.150 and 3.346				6.496
	—	—	—	—
Total, inches				64.965

The determination of the body length only is free in a few cases. When new trains are to be built the best procedure to follow is not to choose the body length arbitrarily and to leave it to the roll designer to get his passes inside the set limits as best he can but after the rolling program has been decided, to choose an agreeable standard body length. The profiles added later must be laid out on a given roll length. Example 1 then should be followed, that is, to balance with the collars, or if this does not work, to group the profiles differently. For example, instead of a 2.757-inch flat with the 3.937-inch, one takes a 2.362-inch if there is not enough room, or a 3.150-inch, if there is too much room. In the second case the last roughing pass is a reserve pass, because the former, due to its small conicity, if worn, requires more turning down than the previous passes. This is avoided if two final roughing passes are provided instead of one. Less wear results but more turning down, while with the other roughing passes there is more wear but less turning down for each 0.04-inch of wear.

The following factors apply to hoop steel and differ with those applying to rolls for steel flats:

1. The smaller thicknesses require less stiffness of the stock; the taper of the pass must therefore be larger to facilitate freeing the stock from the roll. With thicknesses up to 0.079-inch a

taper of 10 per cent is advised, with heavier sections the taper ranges from 5 to 8 per cent.

2. Hoop steel spreads less than flats. In the last passes with hoop steel over 1.181 inches wide it is sufficient to allow a spread ranging from 0.0098 to 0.0197-inch; with narrower widths from 0.039 to 0.079-inch with the first pass. Broad skelp 7.874 inches and over should be given no draft in the later passes if good corners are desired. In the first roughing passes a spread ranging from 0.05 to 0.1 of the draft is sufficient, with small roll diameters less, with large diameters more.

3. The least draft of 0.0197-inch with thin sections, which is necessary to guarantee straight delivery of the hoop steel, results in drafts in the last roughing passes and in the polishing roll of 30 to 45 per cent which are considerably higher than with flats. This is desirable because the thin profiles otherwise would cool off too much.

4. Hoop steel ordinarily is not edged. With special hoop steel profiles with round edges turned-in passes must be used as shown in Fig. 74. They are given a taper of at least 10 per cent and are made

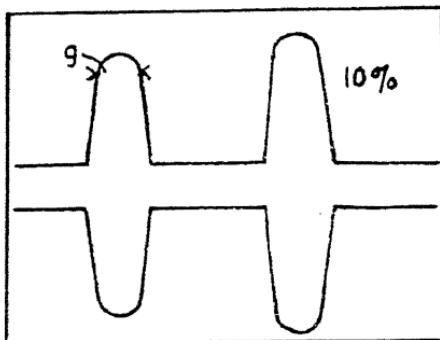


Fig. 74—Turned-In Edging Passes for Hoop Steel

about 0.039-inch broader at the base g , than the hoop steel to be entered, in order to effect easy freeing from the pass. If the rounding should be well developed, the edging should be about four times the size of the radius. Therefore, hoop steel 0.984×0.079 -inch must enter the edging pass with 1.142×0.079 -inch. Hoop steel also is edged to break off the scale, which is accomplished by the bending of the stock in the edging roll. In this case the edging is accomplished in the roughing pass. It must be remembered that edging slows up the rolling.

Fast rolling is a prerequisite for hoop steel to impart a blue color. Cold-rolled hoop steel reduced too cold is red and as mentioned under Item 3, drafts which are too mild from the standpoint of percentage also are detrimental. Instead of an edging roll, in most cases a leader or second polishing roll is provided. Finally, a

chilled ground polishing roll often is required for a clean hoop steel.

Draft stages similar to those given under flats, can be used for hoop steel. A few examples for steel are given in Table IV. For wrought iron the spreads in all passes should range from 0.0098 to 0.0197-inch to get sharp corners.

Stock Spreads Unhindered

With narrow leader and polishing passes the spread is larger, and because the stock is colder it can spread

Table IV

Pass Layouts for Different Sizes of Hoop Steel

HOOP STEEL 0.787 TO 1.181 INCHES X 0.039 TO 0.098-INCH

Pass number	1	2	3	4	5	6	7	8	9	10	11
Draft stage	0	0.059		0.157		0.354					
Pass spread	0.020	.....	0.030	.....	0.039	.....	.....	.....	.....	.....	.....
Taper %	10	.....	10	.....	10	.....	.....	.....	.....	.....	.....
Bevel	0.049	.....	0.059	.....	0.118	.....	.....	.....	.....	.....	.....

HOOP STEEL 1.575 TO 1.969 INCHES X 0.059 TO 0.098-INCH

Pass number	1	2	3	4	5	6	7	8	9	10	11
Draft stage	0	0.079		0.197		0.394		0.591		0.866	
Pass spread	0.020	.....	0.030	.....	0.039	.....	0.059	.....	.....	.....	.....
Taper %	10	.....	10	.....	10	.....	10	.....	10	.....	.....
Bevel	0.049	.....	0.098	.....	0.118	.....	0.157	.....	.....	.....	.....

HOOP STEEL 3.150 TO 4.724 INCHES X 0.098 TO 0.197-INCH

Pass number	1	2	3	4	5	6	7	8	9	10	11
Draft stage	0	0.098		0.236		0.512		1.024		1.969	
Pass spread	0.01-0.02	.....	0.02-0.03	.....	0.039	.....	0.049	.....	0.069	.....	.....
Taper %	10	.....	10	.....	10	.....	10	.....	10	.....	10
Bevel	0.039	.....	0.079	.....	0.118	.....	0.157	.....	0.276	.....	.....

unhindered. With a hoop steel 0.394 to 0.591-inch the spread amounts to 0.079-inch, from 0.630 to 0.984-inch to 0.059-inch, from 1.024 to 1.378 inches to 0.039-inch; and with wider stock from 0.030 to 0.039-inch. The exact width is regulated by the draft.

The thinness of the stock gives the overdraft in the material between the rolls little chance to be relieved. It, therefore, is better to make the overdraft about 0.079 to 0.197-inch for the roughing passes and to use the polishing roll as a friction roll. An example of draft stages for hoop steel follows:

	Hoop Steel 0.787 x 0.049"
Hot profile (0.787 x 1.013) x 0.049	= 0.797 x 0.049"
Leader profile	0.738 x 0.079"
No. 5 roughing pass	0.879 x 0.128"
No. 4 roughing pass	0.659 x 0.187"
No. 3 roughing pass	0.620 x 0.285"

In the pass 0.620x0.285, a 0.511 to 0.571-inch square will enter satisfactorily, and therefore, three roughing passes will be sufficient. Frequently two are used. One then receives from the 0.511-inch square in the first roughing pass a draft which is too high. A smaller square, which does not fill completely must be entered in the first roughing pass. Nonfilling passes always are unequal in width, and this inequality continues to the finishing pass. The final product will be inexact and as the light side work, mentioned with flats is absent, the edges will be ragged. In most cases this is not the fault of the material, but of the pass design and indicates that too large spreads have been chosen.

With flats, the rolling becomes more difficult, as the height approaches the width or in other words, as the profile becomes thicker. This is changed when the height equals the width or when the rectangle becomes a square. In this case the neutral line is not placed parallel to the sides of the square, but laid in its diagonal.

With this method of laying out passes, flat profiles, which are only approximately square, such as 1.575 x 1.496 inches, 0.787 x 0.709-inch, etc., can be rolled if the two rolls are moved sidewise in comparison with one another. In Fig. 75 the lower roll was moved slightly to the right. This method presents certain difficulties, because as with a cross section lying flat, whose height in relation to its width is large the rod may develop a tendency to twist itself like a screw. Different conditions exist with a square profile. Suppose the dimensions of the profile to be entered and the setting of the rolls is exact. If the draft is slight the mentioned tendency ceases because the stock receives a different working in the individual parts of the cross section in two ways:

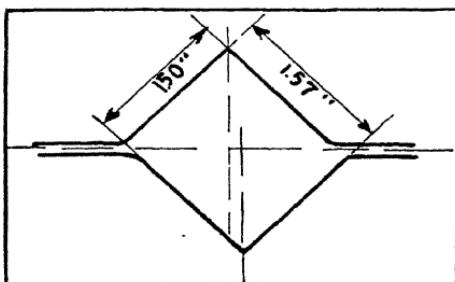


Fig. 75—Pass Design for Rolling Approximately Square Profiles

First.—Imagine the passes I to III in Fig. 76 of a roll exactly square and that the angle α equals 90 degrees. The passes are stepped by 0.039-inch and their sides measure 1.260, 1.220, 1.181 inches. The stock is reduced by passes I, II and III in order, being turned 90 degrees between each pass. As the square sides increase from left to right the diagonal, b_1 , therefore is larger than b_2 ; and h_1 also is larger than b_2 . The case exists, therefore, of a broad profile being entered into a narrower pass. The result is that at the open places $\alpha\alpha$ the steel squeezes out or bulges as shown in Fig. 77. The bulges of pass II come on top in pass III and so increase the draft, while in the horizontal direction a squeezing out of the material again takes place. In the last pass the stock is entered twice but if this should

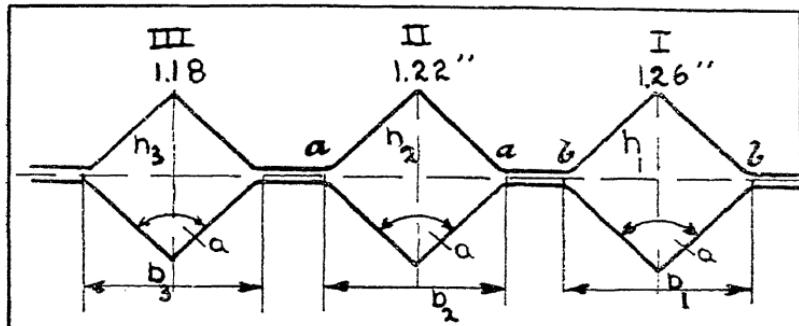


Fig. 76—Procedure for Stepping Up Passes Designed to Roll Squares

cause the stock to come out on the wrong side of the train, it is entered three times, being turned 90 degrees between each pass. The bulges caused by the next to the last or third last pass are rolled out in this way, so that the final product is free from these defects and nearly square in cross section.

According to the foregoing the stock is pressed more in the perpendicular direction and less in the horizontal

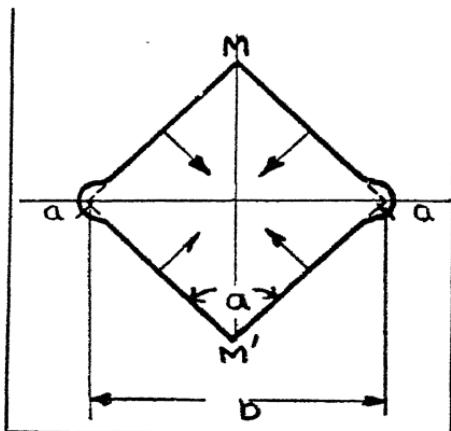


Fig. 77—A Broad Profile Entered Into a Narrow Pass Results in Bulges

and, therefore, is elongated. This explains why with square passes the side parts at a a , which have less draft, are pulled from the middle parts to the right and left of the line mm' and also why they shrink. The shrinkage is represented by the diagonal b in Fig. 77. The result must be that angle α after leaving the rolls is smaller than in the pass. Therefore, to weaken the formation of the bulge, the angle α was made somewhat larger than 90 degrees and the diagonal b also larger than the vertical in the direction mm' . The effect of this change is that the shrinkage of the horizontal diagonal is increased by reason of the fact that more draft exists in the center of the following pass and less draft

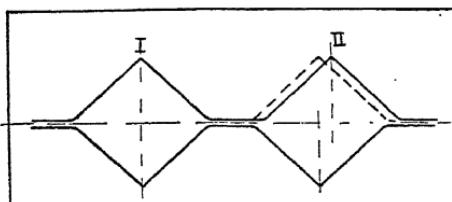


Fig. 78—If Square Passes Are Not Machined Carefully the Halves Will Be Displaced

along the sides. The roof-shaped outline of the square pass, which holds the material together in the direction of the arrows in Fig. 77, makes the entering of a broader pass into a narrower pass possible. Without these influences the stock being reduced would squeeze out at the sides and form a fin.

Due to the shrinkage of the outer parts internal stresses originate, which, insofar as they are distributed symmetrically over the whole cross section as with hoop steel, permit the rod to leave the rolls straight and to spread over the edge parts, which hold back.

Second.—A similar effect is caused by the difference in the working diameter. In Fig. 79, D_a is larger than

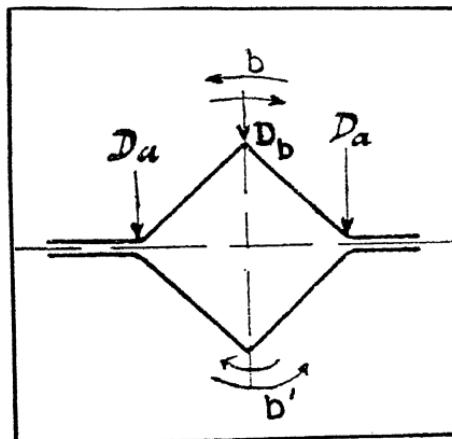


Fig. 79—Large Working Diameters Throw the Surface Parts Ahead

D_b . The larger diameters, D_a , throw the surface parts ahead, while the smaller diameters, D_b , hold the parts in the middle at the line bb' back. Internal stresses must originate, because the different parts of the cross section cannot possibly assume different velocities. Whether those under the first source predominate or not, depends on the size of the roll diameter, the draft and the depth of the pass. In all events the stresses from sources one and two will not be equal. Resultant final stresses will remain, which will guarantee the rod leaving the rolls straight if they are distributed equally over the halves of the pass to the right and to the left of bb' . If not, twisting forces in the direction indicated by the inner

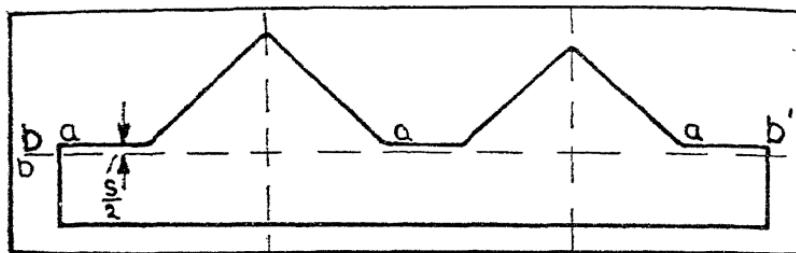


Fig. 80—Diagram of a Double Template Which Simplifies the Laying out of Square Passes

and outer arrows shown in Fig. 79 will become effective.

With accurately turned rolls and equally heated material, the twisting forces can be avoided by a side-wise displacement of this pass or the preceding one. This is not possible under some circumstances if the rolls are not turned accurately, particularly if a pass and the following one of a 2-high mill or the first and third passes of a 3-high mill lie on the same roll but the halves of the pass are displaced in relation to one another as shown in Fig. 78. If pass II is set correctly by moving the upper roll to the left, that is, to the dotted position, pass I will be wrong and vice versa. Exact machining, therefore, is extremely important for rolls with square passes.

Laying the passes exactly above one another can be made easier by using double templates, which always fit into two passes at the same time as shown in Fig. 80. If double templates are used with a square roll from left to right or in the opposite direction all pass centers must lie above one another. Even with ordinary templates the offsets at aa , which rest on the roll body if the template fills the pass should be added. To make it easier to finish the roll drawing the neutral line, bb' , to be laid into the roll line can be scribed on the template. This will be finished only for half the pass although the whole is formed if the upper and lower rolls are turned according to it.

According to the foregoing, the vertical diagonal

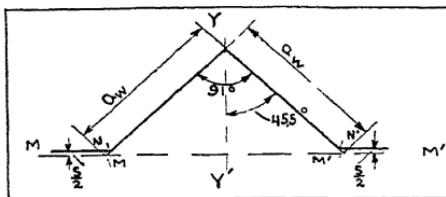


Fig. 81—Construction of a Finishing Pass from the Angle at the Point

must be smaller than the horizontal. The amount of the difference is chosen either by assuming a definite angle α of 90.5 to 91.5 degrees. Brovot recommends 91 degrees for medium size squares, 90 degrees 40 minutes for large, 91 degrees 20 minutes for small. Or a definite relation for the lengths of the diagonals may be chosen. Geuze gives for the vertical diagonal $d_v = 1.40a_w$ and for the horizontal $d_h = 1.42a_w$, in which a_w denotes the side of the square measured hot. Brovot recommends a relation of horizontal to vertical diagonal of 1.0117 for large square profiles, 1.0176 for medium and 1.0235 for small according to the formula $d_h : d_v$. Generally it suffices for all profiles to simply choose α as equaling 91 degrees or $d_v = 1.40 a_w$, and $d_h = 1.42 a_w$.

When the angle or the relation of the lengths is determined a template of the angle 91 degrees, that is 45.5 degrees is used to lay out an angle of 45.5 degrees to the right and left of the vertical diagonal YY' in Fig. 81 and then the side of the square increased by the amount, a_w due to being hot, is measured off. The ends of the legs, mm' , are connected and receive the neutral line. The spring, s , is determined and a line, nn' , is drawn parallel to the neutral line at a distance exactly equal to $s \div 2$. The offsets must rest on the body of the roll when the template enters the whole distance into the finished machined pass. Or axes, as shown in Fig. 82, are drawn; a distance of $(1.40 \div 2) \times a_w$ is laid upwards and $(1.42 \div 2)$

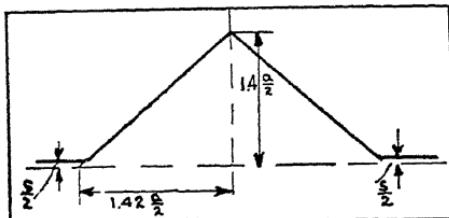


Fig. 82—Construction of a Finishing Pass from the Diagonals

$\div 2) \times a_w$ to each side; and, the procedure followed as previously mentioned.

Provision for the material, which is excessive in width, is made by enlarging or rounding off the pass at both sides as shown in Fig. 83. The dimensions of the fillet radius in the prevention of spread according to Geuze go too far in the estimation of the author. A fillet of this size at least for merchant bars, is unnecessary and requires collars which are too broad. Brovot recommends taking $R=0.35a$. According to the plasticity of the stock, R , the fillet radius, should be exactly equal to a .

If the fillet has been chosen, the steps are determined. Those recommended include:

With a square 3.150" and over	0.197"
With a square 1.969 to 3.150" and over about	0.118"

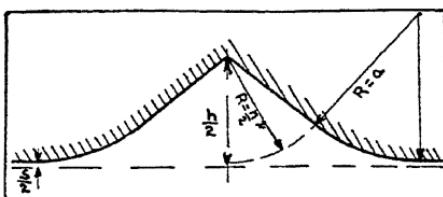


Fig. 83—Finishing Passes Frequently Are Enlarged or Rounded Off at Both Sides

With a 1.260 to 1.969" square, about 0.079"
 With a square 1.260" and under, about 0.039"

If for example, the passes 1.969, 2.087, 2.205 inches, etc., are on the roll and the schedule calls for a 2.047-inch profile, the 1.969-inch pass is used and the rolls are opened up. The spring can be assumed as ranging from 75 to 100 per cent of the step. As the spring becomes larger, the draft increases, and consequently the rolls spring more. The lathe tools, which are finished according to the templates, can be welded to soft-steel shanks to save material. Steels also are available in square shapes as shown in Fig. 84, which rest loosely on the tool holders and are secured by a plug z . Some paper should be placed beneath the point designated a to give a springy support. These tools have the advantage, that their upper surface only need be ground off when sharpening, and that they seldom lose their shape; on the contrary they cut slower than ground tools.

Material needed for rolls is mold cast chilled iron.

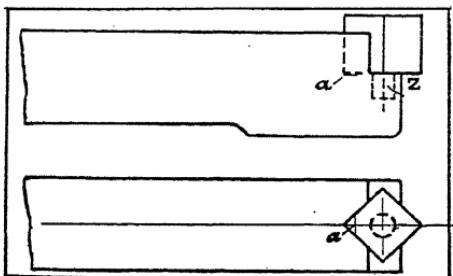


Fig. 84—Lathe Tools Made from a Square Shape

The depth of chill is determined from the deepest pass, plus half the amount which will wear off the rolls, plus an addition ranging from 10 to 30 per cent of the whole depth. The largest pass, for example, is 3.543×3.543 inches. Then the pass depth is equal to half the diagonal or 0.7×3.543 inches = 2.480 inches. The largest diameter is to be 25.591 inches. The roll should be worn down to 21.654 inches. The smallest radius therefore is 1.969 inches smaller than the largest and the depth of chill should at least be equal to $(2.480 + 1.969) \times 1.1$ or approximately 4.894 inches. Where it is not possible to attain such depths of chill, the passes are cast in, so that only the outermost casting skin need be turned off.

All passes of a roll should be put on one drawing to save space; square, diamond and gothic passes can be drawn over one another, because it is not likely that the various pass lines will lead to confusion. Each pass, however, should be drawn separately.

Method Affords Diversified Sizes

The foregoing method of rolling a rod by hand without guides, that is, held with the tongs and entered into the rolls, was until the second half of the last century the only one for the manufacture of squares. With mills of this type the larger finishing passes also serve as leaders for the next smaller finishing passes, and therefore the work of designing the passes ends with the drawing of the finishing contours. The result is that a large number of square profiles can be produced on the same roll, although the length of the pieces is limited. The rod, which is set on edge or with its longest diagonal upright, has a tendency to fall over, that is, the longest diagonal becomes horizontal. This tendency which is prevented by the roof-shaped side walls of the pass, increases as the stock is elongated. The weight of the stock lying behind the mill, influences through the roll plane, the material tending to lie flat in front of the mill and causes it to fall over in the pass. This danger is increased with small profiles, which enter the rolls at

high speed, because their ends whip back and forth. To make both influences harmless, the steel must be guided before being entered into the rolls. This is done by two flat pieces of chilled iron or hardened steel, F_1 and F_2 , as shown in Fig. 85, conforming to the shape of the rolls and into which the shape of the previous pass is machined. It is best not to press them tightly together, but to allow a clearance ranging from 0.039 to 0.079-inch which can be secured by placing wires a of the desired thickness between the two halves. The points of the profile to be entered are guided better in this place, than the square sides in the machined openings. Such

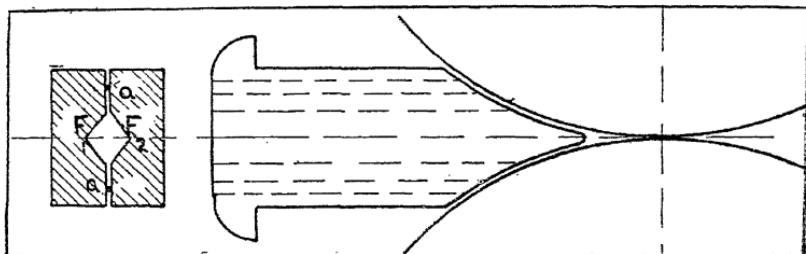


Fig. 85—Typical Guide for Squares Which Is Used to Prevent the Profile from Falling Over in the Pass

a guide, which is used with rounds and fast roughing, has many valuable advantages.

Falling over is prevented, even though the rolling speed and the length of the stock are large. More draft can be given, or in other words the angle α in Fig. 77 can be chosen larger. The higher draft causes spread; that is, the height of the diamond, which goes into the finishing pass, must be taken smaller than the width or horizontal diagonal of the finishing pass. The roller takes it that the diameter going through the guide and finishing pass on edge will fill the latter. This eliminates the superfluous material at the sides usually found with hand-rolled squares. Consequently, it is no longer necessary to round off the sides of the finishing pass nor

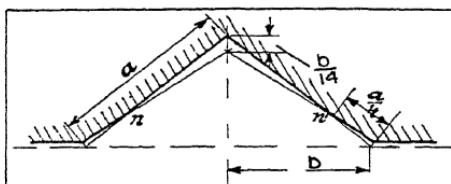


Fig. 86—Easing Off a Finishing Pass of a Guide Square to Prevent Spreading

to subject the piece twice to the action of the rolls.

While the angle α often is taken as 90 degrees it is better with heavier profiles, to choose about 90.5 degrees because even then the draft decreases from a maximum in the middle toward the side. But the spreading effect of the heavy draft in the middle outweighs the shrinking at the sides and, therefore, the steel spreads without squeezing out at the side, if the height of the diamond is exact and the guides are set properly. To prevent this danger an easing at the sides even with guide squares according to Fig. 86, frequently is provided. The result is that the finishing pass either is a true square for profiles 0.591-inch and under or one slightly out of square with which the horizontal diagonals b are 1.42, the vertical diagonals h 1.41 times the hot side of the square and when α is less than 0.59-inch, This is shown in Fig. 87. Therefore, $a_w = 0.013a$, $h = 1.41a_w$, and, $b = 1.42a_w$. The spring from a square 0.197 to 0.984-inch is at least 0.039-inch and from a square 1.024 to about 1.575 inches at the most from 0.059 to

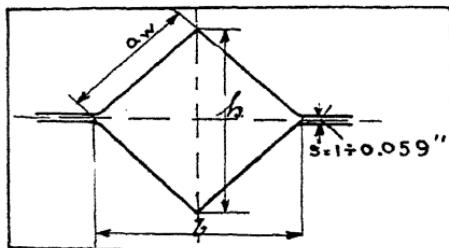


Fig. 87—Finishing Pass for a Guide Square

0.079-inch. The width of the inner collar can be chosen from 0.197 to 0.394-inch and the outer so that the guide boxes have plenty of room.

The roughing consists of either one diamond and one square pass or of one guide diamond, one diamond leader and one square pass. The square roughing pass is taken either from a set of 3-high rolls used for hand squares or from high-speed roughing rolls.

With a square larger than 0.472-inch the roughing pass is taken from the high-speed rolls; with squares from 0.512 to 0.787-inch the roughing passes can be

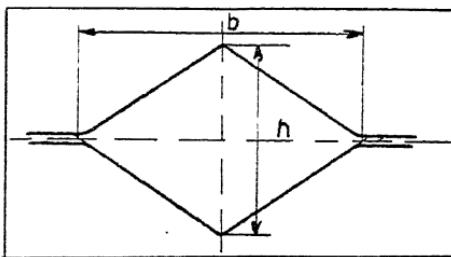


Fig. 88—Construction of a Diamond Pass

taken from either type rolls. When the profile is over 0.787-inch, however, the best practice is to take the square away from the 3-high rolls. Diamond and finishing passes always should be arranged in separate sets. If used on two 2-high sets they should be arranged as the edging and polishing rolls when working flats. The diamond should be placed below and the finishing pass above. Profiles with an area of about 0.217-square inch and smaller are best looped so that they retain their heat. In the construction of the diamond pass the height, h , in Fig. 88, accordingly must be smaller than the horizontal diagonal or according to its size about 0.039 to 0.118-inch (0.039-inch with a equaling 0.157 to 0.276-inch and 0.118-inch with a equaling 1.575 inches) and with immediate values corresponding. The roll designer need not determine this value correctly because it

can be obtained by adjusting the rolls. This is the fundamental difference between guide and hand rolling. With the former the finishing and every roughing pass can be set accurately for itself.

The width of the diamond, b , in Fig. 88, depends on the reduction or elongation desired in the last pass. Kirchberg recommends an elongation of 1.15; others advise 1.1 to 1.15 (larger for small profiles, smaller for large profiles). For alloy steels an elongation of 1.18 from the slender diamond into the finished square is recommended; 1.20 to 1.23 from a square into the slender

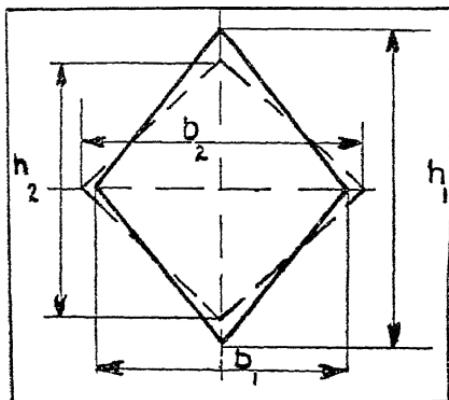


Fig. 89—Square Pass Designed to Take a Diamond Section

diamond; or an angle α of a slender diamond for a square 0.177 to 0.472-inch on a side of 120 degrees, for 0.512 to 0.671-inch on a side of 116 degrees and for 0.709 to 1.024 inches of 112 degrees. If b is chosen a little large, the roller need only enter with a smaller square or an underfilled diamond. The guide diamond will be narrower, and b , therefore, smaller.

If the elongation is chosen, for example, as 1.14 or a reduction of 12 per cent, the cross section of the guide diamond amounts to $Q = a_w^2 \times 1.14$, in which a_w denotes the hot dimension of the desired square side. And as the cross section of the diamond, Fig. 88, consists of four

triangles each having a surface of $(b \div 2) \times (h \div 2) \times (1 \div 2)$, its surface, Q , equals $(b \times h) \div 2$. Therefore, $(b \times h) \div 2 = 1.14 a_w^2$, and, $b = 2 \times (1.14 a_w^2 \div h)$.

In the determination of the diamond roughing pass or the square roughing pass the procedure is the same. The choice of the square roughing pass can be left to the roller, who by adjusting the rolls can compensate for small differences in the dimensions of the pass, the wear and for various widths due to different material and temperatures.

According to the foregoing process, for example, the roughing pass for a 0.630-inch square would be found as follows: (Fig. 88). For a guide diamond, $h = 1.42 \times a_w = 0.079$ -inch; $a_w = 0.630 \times 1.013$ —or approaches 0.638-inch; h —or approaches 0.827-inch; $b = [2 \times 1.14 \times (0.638)^2] \div 0.827$ —or approaches 1.122 inches. For a roughing diamond or a roughing square, $h = 1.122 - 0.079 = 1.043$ inches; and, $b = [2 \times 1.14 \times (1.122 \times 0.827)] \div (1.043 \times 2) = 1.024$ inches.

Elongation Values Recommended

In the case under consideration, a 0.738-inch square with the diagonal 1.033 would be used. Brovot recommends the following elongation for squares of 0.197 to 0.984-inch; from guide diamond to finishing pass 1.1 to 1.2 and from roughing diamond to guide diamond 1.25 to 1.35. Geuze calculates the spread as shown in Fig. 89 with the diamonds as with flats as: $B = b_2 - b_1 = 0.25$ to 0.35 ($h_1 - h_2$) for steel and wrought iron respectively. The draft, which is given the vertical diagonal in the finishing pass, is assumed as $0.15 \times h_1$ while the spread is determined from the foregoing formula, from which both diagonals of the diamond result. A simple construction of the diamond results if the angle at α at the corner is assumed as 112 degrees for a square 0.197 to 0.512-inch; 108 degrees for a square 0.551-inch to 1.024 inches; 105 degrees for a square 1.024 to 1.260 inches; and, 102 degrees for a square over 1.260 inches.

On the vertical line, YY' , in Fig. 90 and from the

point O up and down, one-half the height, equal to one-half the horizontal diagonal of the following pass minus 0.039 to 0.118-inch, is laid off. At these end points one-half the angle α presented in the foregoing paragraph is laid off to the left and right of the vertical and the sides are continued until they cut the horizontal. To transfer the angle exactly is difficult and small differences influence the width considerably, so it is advisable, always to test the width by calculating the reduction or the elongation.

The scale for the angle α proves, that it is chosen

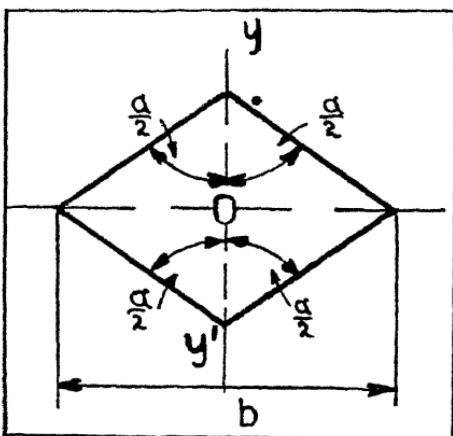


Fig. 90—Construction of the Finishing Pass from the Angle

flatter the smaller the square. The reason for this is the diamond when turned up is more pointed above and below. As the guides, as previously mentioned, are more effective at these points, such slender diamonds will not fall over so easily. On the other hand the draft is larger and, therefore, the dimensions will be more uneven.

From the foregoing a rule has been devised which will repeat itself in the rolling of rounds:

The closer the diamond approaches the square, the blunter it is, the more exact will be the final product, the greater though is the danger of falling over in the pass thus increasing the amount of poorly rolled material. On the contrary the more slender the

diamond and the flatter the angle α , the more inexact is the finished steel, the easier for the guides to prevent falling over.

This inexactness shows that squares from slender diamonds turn out full or have fins on one side, and underfill on the other. If the fault is with the setting of the rolls or inaccurate roll turning, it cannot be avoided by moving the guides.

A combination of hand and guide rolling is the case, if only the second finishing pass is put on a 2-high mill equipped on the entrance side with guides and guide boxes and the various other passes put on a 3-high mill. The roughing pass and the finishing pass then can be set up independent of one another and the advantage of an exact final product and long rolled lengths combined with that of a simple set-up of the rolls. This process particularly is recommended for medium squares 0.630-inch to 1.378 inches and can be used for squares 0.472-inch and smaller. Squares between these ranges can be made in this way, but it is better to use the diamond passes.

Relation Is Fundamental

The rolling of squares was discussed in detail because it is fundamental for the following sections, and because the steps involved are complicated. This follows from the fact that the draft can be varied between wide limits. For example, the same size clearance can be used and a clean profile obtained when entering a 1.280-inch square into a 1.181-inch square pass, which gives an elongation of $(1.220^2 \div 1.181^2)$ or 1.07 as when entering a square of 1.260 inches, which corresponds to an elongation of 1.14. A clean profile, however, depends on a certain automatic regulation of the average increasing contraction of the outer cross-sectional parts as a result of the increasing draft and also of the roof-shaped side walls of the pass.

The important advantage of guide rolling is, that every pass is a leader and a finishing pass, which permits finishing many profiles on one set of rolls. For

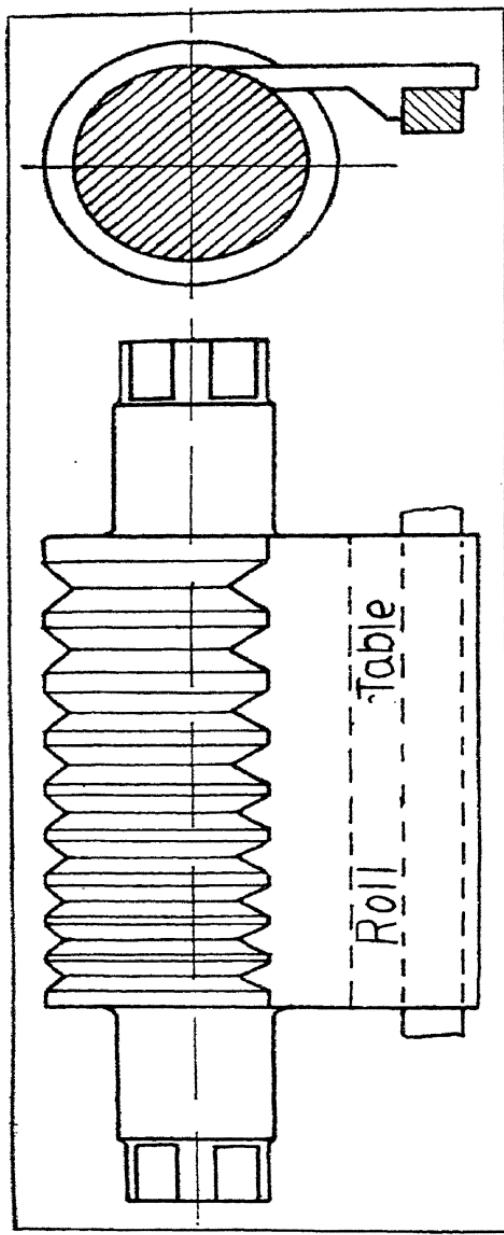


Fig. 91—Roll Table Which Serves as a Stripper Guard and Obviates the Use of Entrance Guides

example, all dimensions from 1.417 to 2.756 inches can be finished in any desired size on a single 3-high mill. It is not necessary to change rolls or move guides. These can be left for all profiles. In most cases they are combined with one another, to make a stripper guard and guide similar to that shown in Fig. 91. Entrance guides are not necessary.

With hand rolling of squares and rounds the shrinking at the ends of the horizontal diagonal frequently leads to the formation of cracks.

Hand Rolling Preferred

Hand rolling should be used for profiles 0.787-inch and larger; and, where only small quantities of a size are ordered. If a 3-high set is used for hand rolling in addition to the roughing rolls the pieces coming from the roughing rolls in the square can be brought to the proper angle and exact dimension before entering them into the flat or shaping rolls.

Guide rolling should be used where large orders of one dimension are to be finished. Guides should be used when rolling profiles smaller than 0.512-inch.

Hand rolling of rounds is similar to the process of hand rolling squares. A 3-high mill usually is employed. The stock is turned 90 degrees after each pass. The tendency to fall over in the pass, however, is greater, because the roof-shaped side surfaces of the square become circular from the edge position of the largest diameter to the horizontal position. The result is, that the rod immediately after entrance turns to this position, if not prevented. A guide naturally cannot hold a round rod, so that it must be done by hand. One to four men, according to the size of the section, hold the rear end of the piece tightly and, thus, counteract the twisting forces. Even then the piece turns as soon as it becomes elongated from 26 to 32 feet. This process seldom is used and has little value, other than the rolling of small quantities of rounds for plant use or of special steels.

It is mentioned merely to clarify the subject of guide rolling.

As with the hand rolling of squares the round passes, which with a similar stepping lie alongside one another, serve as leader and finishing passes. The steps purposefully are taken somewhat smaller than with the squares and range between 0.039 to 0.157-inch. The round profile does not keep its shape as well as the squares when the rolls are raised and the arc becomes indefinite. If the

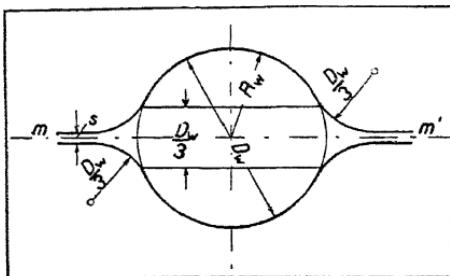


Fig. 92—Construction of the Finishing Pass of a Hand Round

arc is too large, the error is small. To overcome the stepping, the rolls are lowered rather than raised. The space between the rolls, designated s in Fig. 92, is made to equal this stepping plus the spring. Little draft is applied to hand rounds and hence the spring of the rolls is small. It is sufficient to allow 0.098-inch as the spring for roll diameters up to 2.362 inches. If steps of 0.118-inch and later of 0.079-inch are chosen and the finishing passes are arranged as 2.362, 2.244, 2.008 inches down to 1.929, 1.850, 1.772 inches, etc., s should equal $0.118 + 0.098$ or 0.216-inch. The outer collar should be between 1.969 and 2.362 inches and the inner collar between 0.394 and 0.787-inch.

Two or three roughing passes are arranged before the last finishing pass and in the foregoing example are 2.480 and 2.598 inches. These passes, similar to those of hand squares, are made slightly larger at the sides. A number of constructions are possible; one which has

given satisfaction is shown in Fig. 92. D_w , the desired diameter of the round, multiplied by 1.013 gives the hot dimension. An arc with a radius R_w [$R_w = (D_w \div 2)$] is drawn between the top of the pass and one of the parallels to the neutral line MM' at a distance equal to the pass outline, $R_w \div 3$. From there on the pass is widened by an arc with a radius equal to $D_w \div 3$, which is tangent to the arc and the outline of the roll.

How Bulge Is Eliminated

Under operating conditions a rod from the roughing rolls, gothic or square shaped and with blunt corners, is entered in a 2.598-inch pass. A part of the material flows to the side and forms a bulge. The rod is turned 90 degrees and entered into the 2.480-inch pass. The bulge, which now lies above, is rolled in and gives the profile increased draft in the center. Bulges again are formed at the ends of the diagonal now lying horizontal, which are rolled out in the 2.362-inch pass. The stock is entered in this pass twice. Only the bulges give the profile draft because the diameter is not decreased during the second passage through the rolls. The slight draft results in smaller bulges. If the piece is entered a third time, the draft is still smaller and again will have a correspondingly smaller bulge, etc., until after the third to the fifth passage the profile is commercially round. The bulges cool more than other portions of the profile and therefore easily are recognized as shadows. The roller guides the piece so that this shadow always is on top. Because of the light draft in the finishing pass a more accurate contour can be obtained than is possible with guide rounds.

As mentioned in discussing guide squares, a square profile turned on edge and pressed from above gives a diamond and the diamond pressed on edge results in a square. The corresponding process with the round would be to press a circular section to an oval and to set this on edge and by pressing from above to change it to a round profile. This second part of the process is

used in the guide rolling of rounds. The oval though is not formed from a circular, but from a square profile, which is entered flat into the oval as shown in Fig. 93. The changing of a square into the round cross section occurs more rapidly by this arrangement than in hand rolling. The square and oval passes also are used for roughing work.

The transformation of the oval into the round section no longer corresponds to the rule of low draft in the finishing pass. The oval, the same as the diamond,

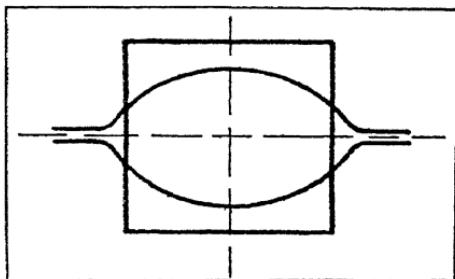


Fig. 93—Oval Pass Designed to Take a Square Section

is held mechanically with the guides to prevent its falling over in the round pass. The guides each carry slightly less than half of the oval, and are held apart by wires placed between.

With rounds up to 1.181 inches diameter the finishing pass can be made round and d_w is chosen to equal 1.013 times the diameter of the cold section. The enlargement at the sides can be omitted. The corners are rounded off somewhat at a , as shown in Fig. 94. The radius equals $0.05d$; the spring, s , ranges from 0.039 to 0.059-inch; the inner collar ranges from 0.197 to 0.591-inch; the outer collar ranges from 1.969 to 2.362 inches according to guide boxes; while the stepping is 0.039-inch or smaller.

The work is made easier for the rolling foreman, if given slight relief at the sides, because the tendency to

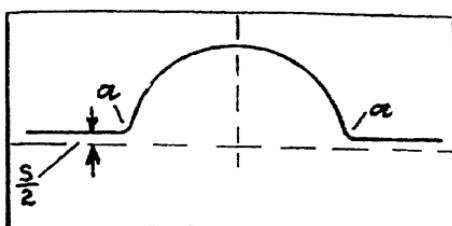


Fig. 94—Finishing Pass of a Guide Round

form fins then will cease. This can be done by using the turning tool of the next larger pass, which is about 0.039-inch larger, so that the same amount of material is scraped off to $\frac{1}{4}$ the pass depth as shown in Fig. 95. With the rounds larger than 1.181 inches it is advisable to consider the shrinkage of the side parts of the round, which have no draft, by taking the horizontal diameter somewhat larger. According to Kirchberg this should be about 2 per cent as shown in Fig. 96.

The oval set on edge must be higher, but narrower than the diameter of the round, so that it can have draft and can spread. The spread does not increase proportional to the total width as with flats. It can be taken as 0.039-inch for small profiles from 0.157 to 0.394-inch and as 0.157-inch for the large profiles 7.874 inches with corresponding intermediate values.

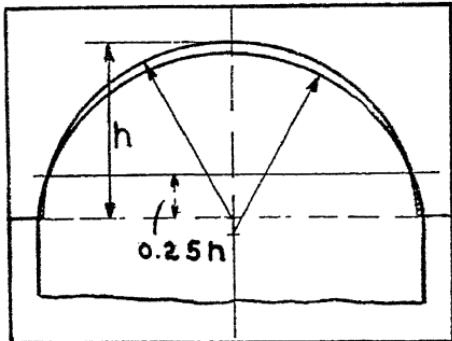


Fig. 95—A Slight Relief at Sides of Next Largest Pass Eliminates Fin Formation

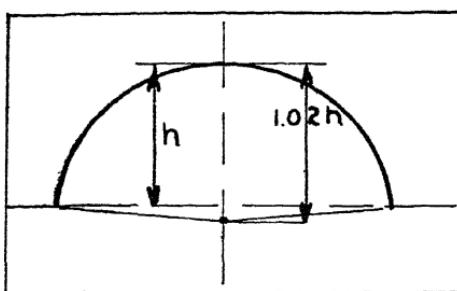


Fig. 96—Finishing Pass for a Large Guide Round

The exact height is obtained by adjusting the rolls. A large spring is allowed in the oval so that an oval, which is too full, can be corrected. With a 1.575-inch round the spring ranges from 0.059 to 0.118-inch while with a 7.847-inch round the spring ranges from 0.118 to 0.394-inch. Kirchberg, under the supposition that there will be sufficient adjustment by moving the rolls, gives a spread of 0.079-inch for sizes ranging from 0.394-inch to 6.496 inches. For the dimensions under 0.394-inch he recommends the relation between the height of the oval h and the diameter d of the desired round shown in Fig. 97, as d equals 0.394, 0.354, 0.315, 0.276, 0.236, and 0.197-inch; and $h \div d$ equals 0.8, 0.797, 0.790, 0.777, 0.751 and 0.7 respectively. Geuze recommends a relation $h \div d$ as 0.785 for rounds ranging from 0.157 to 0.394-inch and as 0.8 for rounds ranging from 0.433 to 1.378 inches. The latter recommendation for the heavier sections, gives an oval which is too light and subjects it to too great a change of shape in the last pass. To set down the spread as a definite relation to the total width, that is, to the diameter of the round may lead to erroneous calculations.

With the spreads ranging from 0.039 to 0.157-inch the inside limits for all diameters, which can be corrected by raising or lowering the oval rolls, are maintained.

For the determination of the spread of the oval, b , in Fig. 97, two suggestions are presented. Geuze uses $1.6d$

as the spread of the oval for rounds from 0.157-inch to 0.394-inch and 1.5d for rounds from 0.433-inch to 1.378 inches. Kirchberg requires an elongation of 14 per cent from the oval to the finished round. If the cross section of the former equals Q and the diameter of the hot profile equals d , then follows the relation:

$$Q = \frac{3.1416d_w^2}{4} \times 1.14$$

The surface of an oval of the width b and the height h can be set approximately as $(2b \times h) \div 3$, the surface of the parabola. Then,

$$2b \times h = \frac{\pi d_w^2 \times 1.14}{4} \times 114; b = \frac{\pi d_w^2 \times 1.14}{2h} = \frac{3 \times \pi d_w^2 \times 3.42}{8h}$$

because in a 1.181-inch round ($d_w = 1.181$), for example, h equals or approaches 1.102. Therefore,

$$b = \frac{\pi \times 1.395 \times 3.42}{8 \times 1.102} = \text{or approaches 1.693 inches}$$

A simple construction, which for rounds up to 3.150

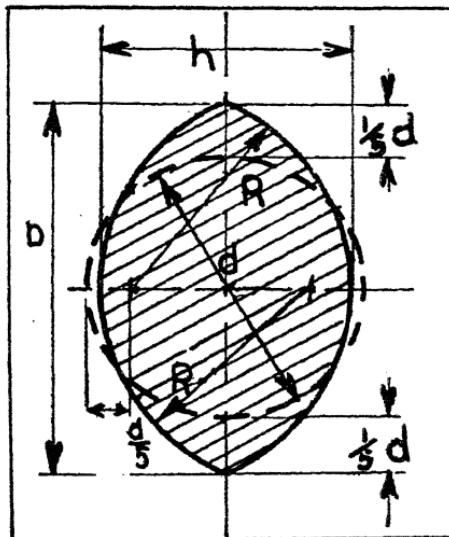


Fig. 97—Round Pass Designed to Take an Oval Section

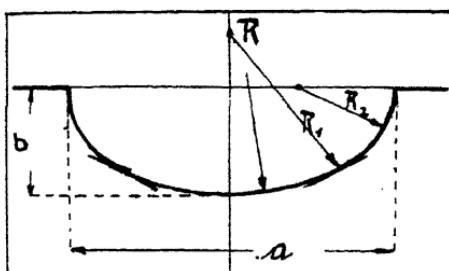


Fig. 98—Round Pass Designed to Take Large Oval Sections

inches gives good results, is presented in Fig. 97 without additional information. For rounds over 3.150 inches the construction is given in Fig. 98. For the former it is better to allow a slightly smaller draft and therefore a spread of $1/6 d$ instead of $1/5 d$, as shown in Fig. 97. The smaller draft is recommended for wrought iron.

Rule Gives Good Results

A rule for rounds from 0.197 to 3.150 inches which gives satisfactory results is $h = d - (0.039 - 0.157\text{-inch})$ and, $b = 1.18d + k$ where k for steel equals 0.079-inch and for wrought iron 0.039-inch. For the control of the oval in practice an approximation can be used, namely, $b = 1.2d + k$. The latter rules hold for the stock and not for the pass as the foregoing figures do. The stock should not entirely fill the points of the pass, but should be slightly blunt. If the rules are used in the design of the rolls, it should be remembered that the oval according to its size will underfill from 0.039 to 0.118-inch; the pass, therefore, should be that amount broader.

In determining a square to be entered into a flat-oval pass, Geuze sets the square side a for a round of the diameter d for small profiles as $1.1d$. The rule, which gives a total elongation of 35 per cent reduction from the square to the round finishing pass, which equals or approaches 1.54, also gives good results for profiles up to 3.150 inches and is recommended. Kirchberg requires

an elongation of about 1.3 from the square to the round. The surface of the square then is:

$$Q_q = \frac{\pi d_w^2}{4} \times 1.3 = a^2$$

$$a : \frac{\pi d_w^2 \times 1.3}{4} = 1.01d_w$$

This formula gives less elongation and is less desirable. The fuller the oval, that is, the more it approaches the round cross section, the smaller the reduction and the more exact the round will be in width. The more even a round is in its horizontal diameter, the more easily it falls over and, hence, overfills to produce defective material. The elongation, therefore, according as a greater or lesser accuracy of the finished stock is desired, is varied from the square to the round between the foregoing limits and between the more or less slender ovals of the previously discussed constructions.

In order to overcome the production of improperly rolled material, the author built a device shown in Fig. 99 to be set up behind the finishing roll. The arrangement consists of a pair of small, idle vertical rolls, *a*,

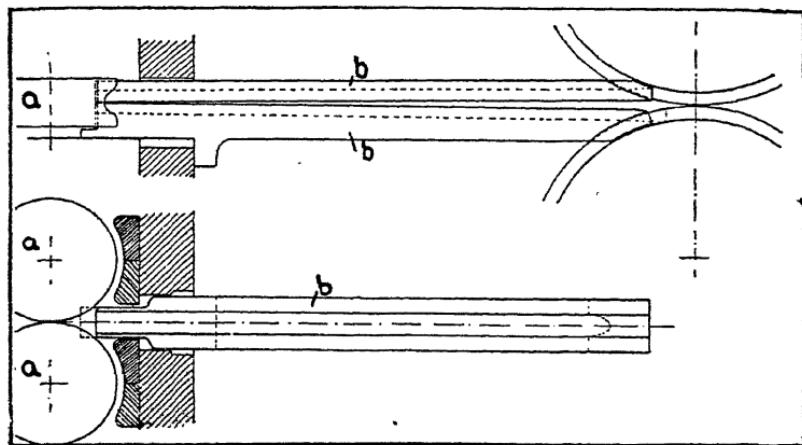


Fig. 99—Details of Finishing Mill Tubular Guide

which operate in ball bearings; half of each roll is rounded off at the sides. A two-piece, tube-shaped, stripper guard, is provided to receive the piece as it comes from the rolls and lead it to the vertical rolls, where it is passed between without bending outwardly. The horizontal spreading diameter, which in these rolls becomes the pressed, is brought to an exact dimension. In order to insure the stock being pushed through vertical rolls, the draft can only be made a few thousandths of an inch or about 1 per cent of the diameter of the round. This is desirable because slight draft in the finishing pass gives accuracy to the final product. The danger, which otherwise would exist with low draft causing the round to fall over or leave the rolls crooked, disappears. The reason for this is that the guide in front of the horizontal rolls holds the piece upright. Moreover, since the stresses from the horizontal rolls are preserved in the vertical rolls, a straight exit is obtained.

Delivered in Accurate Dimensions

The device delivers screw stock with an accuracy almost equal to that in drawing. An additional advantage is that if the rounds are coming too broad on account of the oval being too high, the device will have too much draft and will be pushed away. For this reason it is attached to the housing with small screws. If the roller underfills the rounds, the vertical rolls will stand idle and if the night shift uses the apparatus without interruption, inspection will not be necessary in that the product will conform to specifications.

Rounds from 0.157 to 0.472-inch to be drawn after rolling usually are coiled. The manufacturing process is similar to that of rounds, except that in order to increase the production of the train, from two to six wires are run alongside one another in each stand. Each wire is entered once in each stand, and is changed from a square to an oval by an automatic guide and from an oval to a square either automatically or by hand. The latter

process mostly is used. The automatic entering into the square pass is difficult, because the oval must be turned 90 degrees. In addition the guide is set tight to hold the piece rigidly and for this reason the oval must be pushed into the pass with considerable force. This is difficult to do with the red hot stock, which bends easily. The passes are designed for slender ovals in order that the guides may be held together sufficiently to prevent the stock

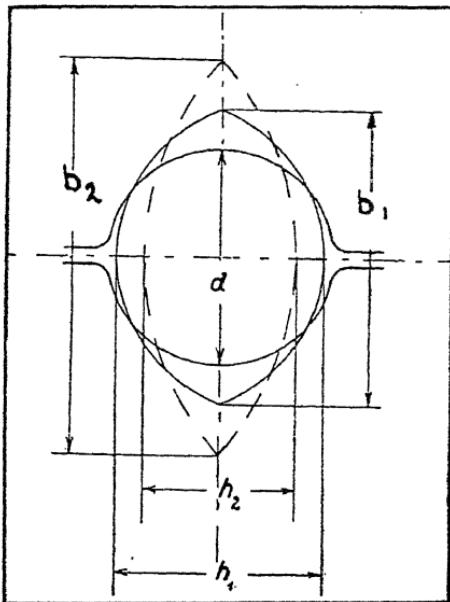


Fig. 100—Design of a Slender Oval Pass for Wire

falling over. Considerable importance is attached to the square in front of the guide oval. If an elliptic cross section with a slight difference between the axes b and h in Fig. 100 is taken, little draft ($b_1 - d$) and little spread ($d - h_1$) results. Small draft is indicative to small spread. A similar regulation is associated with the oval. If the same cross section with the lower height of oval, h_2 , is entered a larger width, b , results because with the

larger draft the steel will spread more. If the oval to the round pass has much spread, in other words, if it is held down, it therefore automatically receives considerable draft. Consequently, it is essential to have an accurately turned and adjusted round finishing pass and square pass. The oval within certain limits adjusts itself or can be regulated by the position of the top roll. These relations also are expressed in the following table:

Guide Oval and Guide Square for Round Wire

Side of square, inch	Dimensions of guide oval, inch	Finished round, inch
0.197	0.341×0.134	0.197
0.207	0.243×0.138	0.197
0.197	0.315×0.148	0.197
0.197	0.315×0.138	0.197
0.197	0.323×0.138	0.197
0.197	0.315×0.118	0.197
0.197	0.355×0.138	0.197
0.197	0.305×0.118	0.197
0.197	0.355×0.150	0.197
0.216	0.374×0.157	0.216
0.236	0.413×0.169	0.236
0.256	0.433×0.177	0.256
0.276	0.472×0.197	0.276
0.315	0.512×0.236	0.315
0.374	0.551×0.266	0.354
0.413	0.630×0.295	0.394

In the table the side of the square is equal to the diameter of the wire. The difference of the oval in lines four to eight is due to the temperature and hardness of the wire and the roll setting rather than a variance in the shape of the pass. It equalizes itself in the finishing pass because the cross section is the same. Where it is, as for example in line six and eight, chosen smaller, the wire becomes less full. How far this should be empty or full, depends on the conditions in each place. The fuller it is the rounder the wire. The first and last ends of the wire usually show certain differences in the temperature and in the hardness or density.

The danger that such wide unsimilarities lead to, the finishing pass being overfull to a fin formation and consequently to a scrap loss, is smaller the further the

average wire cross section is from the full pass cross section.

The difference between wire mills and other mills can be summed up as follows:

1. The stock is not turned out straight, but immediately behind the finishing roll is coiled. In this way it is possible to have long lengths. The coils generally weigh from 100 to 130 pounds, or on an average of 120 pounds; with 0.197-inch round wire the rolled length will be 1100 feet. The long lengths are desirable not only from the standpoint of production, but also from the point of further working.

2. The stock is entered in each stand only once, either in the continuous-type mill or alternately above and below in the open-type 2-high mill; with the continuous process the stock is in many of the passes at the same time and its cooling is kept comparatively small and uniform in spite of its length.

3. The roll speed is higher than on other mills. With open mills it ranges from 25 to 30 feet, with continuous mills from 33 to 36 feet a second. The pauses in rolling in the finishing set in comparison to the rolling period will be small, and in spite of the high rolling speed the capacity of the finishing roll is not sufficient for the requirements. Several wires, therefore, are rolled simultaneously to increase the production.

Little Reduction Afforded

The long lengths with small cross sections give low rolling temperatures in the last passes and, therefore, little reduction at this stage can be given. Small drafts are chosen for wire because sometimes these drafts are dependent on the size of the loops. At other times the passes, which are in use without interruption, are more subject to wear. This is avoided to a certain extent by using tough chilled rolls with the depth of the chill about 1.811 inches. An example of wire passes, taken from the collection of Brovot is shown in Fig. 101. The squares enter the ovals in a flat state according to the dotted line. The resultant ovals are turned on edge by the guides held tight by the short and compact guide box fastened on the rolling beam, and are forced into the square.

With the continuous trains, the entering from one pass to the next is done automatically by repeaters. These take the stock from one roll and, eventually imparting the necessary direction, guide it to the next roll. In the open mill automatic guiding was tried for both passes

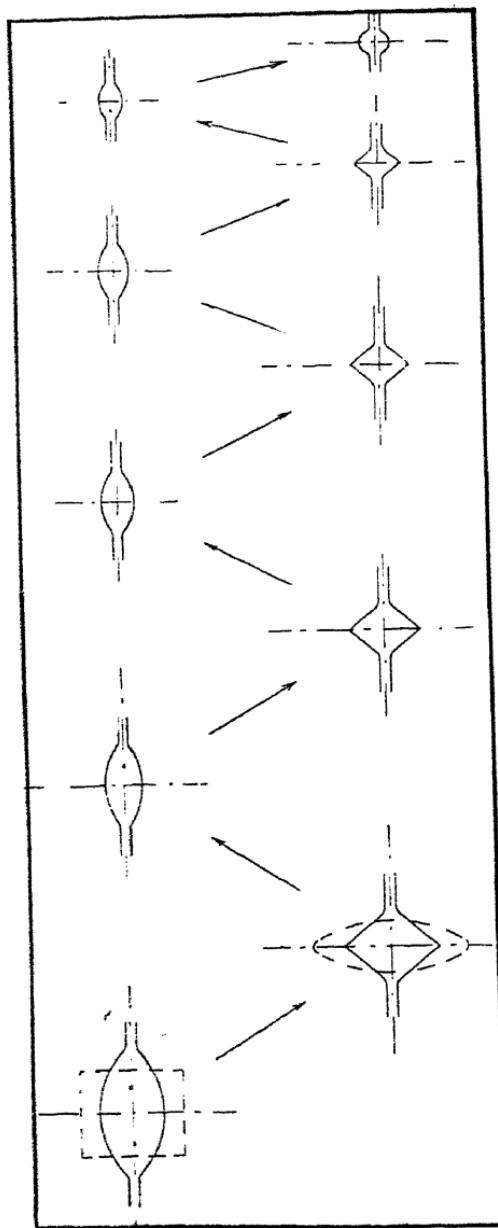


Fig. 101—Example of Wire Passes. The Squares Enter the Ovals in a Flat State, Are Turned on Edge by Guides and Are Forced into the Square

and was found to work where the square is led to the oval. The square, as it leaves the pass, rushes in a diagonal position in an arc to the next roll, but lays flat the instant it hits and enters the oval centrally. A side guide is necessary in front of the pass, so that the position of the wire in going through the oval pass is not influenced by the hitting or whipping action that occurs shortly before the end. It is different with the square pass. The oval will fall over if not held tightly. The thin, oval-shaped, hot, plastic wires, however, are hard to enter. Guides for entering ovals smaller than 0.787×0.315 -inch into a square pass seldom are used. Since the finishing pass is set in above, the guide oval lies below, the square above, the smallest stretching oval below, stretching square above, etc. Consequently, all squares lie above and run toward the exit side of the finishing stand; the ovals lie below and run in the opposite direction.

Position of Passes Avoids Spring

Sources of error which underlie the wire mill do not present themselves with other roll trains. With the open trains two sources prevail. First, the rolling of several wires alongside one another on the same roll, especially the finishing roll. When one of the wires reaches its end immediately the spring of the rolls becomes smaller; the pass becomes lower and the oval, receiving a larger draft in the finishing pass, spreads more. The remaining wires assume a larger diameter in the direction of the roll axes. The original condition is restored when the next wire is entered and remains until another wire leaves the rolls, etc. If the pass is at the end, the movement is at an angle as shown in Fig. 102. To avoid the latter form of spring, the position of the passes on the roll is made symmetrical. First, the two inner and two outer are used, then the two outer, the two inner, etc. As the wear of the passes varies inequalities soon take place in the position on the roll body and an angular spring re-

sults. This different spring of the rolls makes exact shaping of the wire impossible to attain with the guide rounds.

The second reason is that with guide squares and rounds, the most exact setting of the press is required. If the first of six passes requires a small correction of the top roll to the left, the second probably would require a movement to the right, the third would stand right, etc. The correction of the first spoils the third and increases the error of the second. Even if it were possible

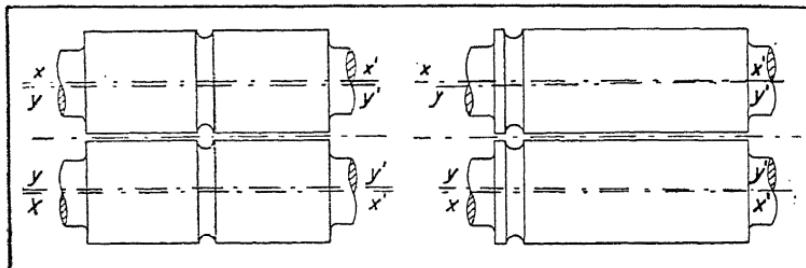


Fig. 102- -Difference in the Spring of the Rolls According to the Position of the Pass

to make the passes mathematically equal and the same distance apart, and to enter mathematically equal ovals through accurate guides then the wear never would be the same and this alone would require different corrections of the position of the roll in height as to the side. As this is impossible where the passes lie on the same roll, the roll foreman must average down.

These two sources of inaccuracy of the finished wire would be avoided or lessened if the wires, running parallel, were entered on different rolls; or if reduced on a single roll designed to handle from two to four wires. In the latter case the averaging would only be necessary between two passes and the change of spring would only occur half as often. The oval passes are less sensitive, and, in addition to the stretching passes lying ahead of the square, can remain on the same roll. This process

would give more exact wire and lower costs in the drawing plant, but would require more rollers. With continuous mills greater speeds are permissible because of mechanical guides. With open trains the exit speed of the previous roll, a_x , is chosen larger than the entrance speed of the following e_{x+1} , so that between the two passes a slowly increasing loop is formed. With continuous mills e_{x+1} is made about 2 to 3 per cent larger than a_x , so that the second pair of rolls draws the stock slightly. A rod leaves the roll with a certain speed gain, which is dependent on the temperature, the water cooling and the draft. Therefore, if the values of the diameters and the number of revolutions of both rolls were chosen as x and $x+1$ so that the mentioned speeds would turn out the same, a play or pulsation between drawing and draft would result. A correction usually is made to throw the difference between the speeds e_{x+1} and a_x to drawing with the continuous mills and to the side of loop formation.

Tension Causes Differences

Drawing complicates the rolling process. It directs the material displaced between the rolls in a forward direction. This is desirable because it increases the elongation and diminishes the spread. Since the spread is no longer dependent on the draft and the size of the roll diameter but on the drawing behind the roll, certain differences can occur. When the rear of the billet has left the first stand of the continuous mill, the tension in the piece between this and the following stand ceases, because a connection between the two no longer exists. If the billet has a cross section of 2.362×2.362 inches and the distance between the roll stands 3.9 feet, then the cross section of the billet, which was not drawn, is somewhat larger than the previously drawn part. The 3.9 feet in the finished 0.197-inch wire amounts to 3.9×5.579

_____ = 702 feet. If the distance between the second and 0.031

third stand is 3.9 feet and the reduction 40 per cent in the second, it amount to $0.6 \times 702 = 421$ feet, etc. The cross section on the whole length of the wire, therefore, is stepped so that the front end drawn between all stands is the smallest and the rear end the heaviest. A part of these inequalities is rolled out in later passes, if one or more open stands are set up behind the continuous mill.

Difference Is Equalized

An equalization of the difference in the thickness can be brought about by giving little draft in the first pass of the open train. This can be done either by arranging two squares behind one another (the last pass of the continuous and the first of the open train) and turning the stock 90 degrees between these two. The advantages of this arrangement is that all four corners of the square are developed equally at the beginning of the open train. Or the first pass of the open train can be used as an oval with less draft. In both cases the inequalities of the continuous mills are eliminated before passing into the finishing rolls.

Individual stands of rolls each must have a different gear reduction set to obtain the proper speed. The increased power necessary is almost entirely evened up, in that the short rolls of the continuous train can be given smaller diameters. Because of the tension between stands they will give more elongation and less spread than open rolls with long bodies and with the large diameter.

On continuous mills, a smaller amount of power is required per ton of elongated material than on open mills in spite of the large bearing and gear friction. This presumably is due to the small spreading losses and to the higher rolling temperature. The latter advantage rests on the greater rolling speed and wears the finishing pass less. On the contrary a disadvantage of the rolling, is that the wire scales more. In the open mills the scale falls off more with decreasing temperature, a proceed-

ing which is also promoted by the loop formation and the loop and entrance guides.

The elongating passes will suffer more than with the open mill, due to the increased slip between roll and stock caused by the known drawing. The floor space required for continuous mill is less than with the other, as is also the accessibility and oversight. Finally, the additional inconveniences of the continuous trains are the dependence of the distances of the pitch line diameters of the gears of the individual stands and the necessity, in turning the rolls, always of keeping the same diameter relation. It is advisable to keep whole sets of

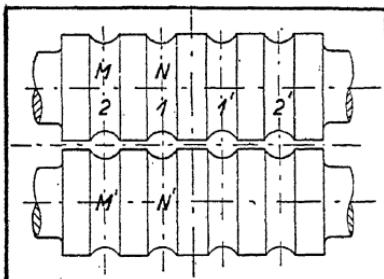


Fig. 103—The Life of Continuous Rolls Can Be Extended by Turning Them 100 Degrees

rolls together and to turn them down with one another. Continuous rolls can be used on one side, and, after the pass is worn, can be turned 180 degrees as shown in Fig. 103. The new pass $1'$ then will be in the place of 1 , and $2'$ in place of 2 , the guides remain in axes MM' and NN' .

In designing a new wire train or in rebuilding an available unit, it is customary to start with the production desired an hour in the principal dimensions to be rolled.

For example, suppose the mill is required to roll 350 tons of 0.197-inch diameter wire in 24 hours, that the loss of time due to working pauses amounts to 10 per cent and that for 10 per cent of the time no steel is

Table V

Calculation of Exit and Entrance Speeds, Roll Diameters and Revolutions Per Minute

NOTE: The figures above those in parenthesis, denote changes made according to calculations given in the text.

in the rolls. To attain this production more passes are provided in the last stand than are given by the calculations so that at least one pass always is available to enter stock.

The highest revolution per minute with a roll diameter of 11.024 inches in the finishing stand is 600 which corresponds to an exit speed of $(11.029 \times 3.1416 \times 600) \div (12 \times 60)$ or 28.8 feet a second. A foot of a 0.197-inch round weighs 0.104-pound. Therefore, a pass will produce without interruption $3600 \times 28.8 \times 0.1$ or 10,368 pounds in an hour. If the working and pass pauses are considered each pass in 24 hours will produce $24 \times 0.8 \times 10,368$ or 90 tons. To obtain the desired production four wires are run through the finishing stand simultaneously.

Determining Rolling Speed

The mill chosen is of the semicontinuous type. To determine the rolling speed in the next to the last stand, the reduction relations, the elongation and the size of the loops first must be decided. The former are received from the pass design. The pass dimensions are entered in line 3 the pass cross section q in line 4 and the elongation n in line 6 in Table V. For the last pass, No. 20, the length of stock, l_{20} , if to be delivered in coil form will weigh 130 pounds and will be $130 \div 0.1$ or 1300 feet long. This is entered in line 5. The number of wires m in line 15 is determined as four.

The circumference speed of the roll or the exit speed of the wire in the finishing stand is 28.8 feet a second as previously calculated. The slight speed gain is neglected because it is nearly the same for all passes. The entrance speed, e_{20} in line 9, is $28.8 \div 1.13$ or 25.6 feet a second. The length of the stock in front of the finishing pass is smaller than behind the roll by an amount equal to the elongation or $l_{20} \div (n_{19} \text{ to } 20)$. As this length must enter the roll at the same speed it leaves the previous stand, therefore, $e:a$ has the same relation as $(l \div n) : l$. From this $e = (a \div n)$ is derived. The roll diameter D is

as 11.024 inches and the speed 600 revolutions a minute;

the time required for a pass t_{20} in line 11 is $\frac{l_{20}}{a_s} = \frac{1300}{28.8}$

or approaches 45.5 seconds. Finally the volumes are calculated $q \times n \times e \times m$, which are drawn into the particular roll per second, or $0.029 \times 1.13 \times 25.5 \times 12 \times 4 = 40.89$ cubic inches for the finishing pass the unknown quantity is the size of the loop. The shorter the loops, the warmer the finished wire will be. This in addition to the saving of the pass, and to the uniformity of the temperature of the front and rear end, is desirable. On the other hand a certain size of loops should be maintained because otherwise the tendency for the end to whip will be too great. This lower boundary of the loop trough is given as 39.4 feet which is equal to 78.8 feet of wire length by the experienced. It is divided first into the length of wire which a roll, x , throws out in the rolling time, t_x , in excess of that taken by the roll $x+1$. This is designated as the secondary or theoretical loop length. It amounts to $t_x (a_x - e_{x+1})$.

Primary Loop Length Is Available

The second part called the primary length of loop consists of about 15.7 to 23.6 feet which is thrown out by the roll x , until the catcher guides the forward end with the tongs, and enters it in the roll, $x+1$. In the latter case according to the skill of the catcher a primary loop length from 15.7 to 39.4 feet is available, both kinds of loops being assumed as 23.6 feet for simplicity. The loop should not be smaller nor in excess of the amount given by the loop trough. These troughs have a 10 to 15 per cent slope. The wire loops of each stand can be directed away from the set in these troughs without touching the other rolls. The length of this trough is estimated between 49 and 82 feet, which therefore corresponds to a total loop length of 98.4 to 196.9 feet. If a loop length is chosen which must lie between 23.6 and 196.9 feet, about 134.5 feet is equal to a theoretical loop

length of 114.8 feet, the entrance speed of the last pass is determined by the exit speed of the previous pass: from this result and the elongation, its entrance speed is determined; from this and the next loop length the exit speed with the third last stand is determined, etc. However, the best results are not obtained by calculating on this basis. The rolling speeds are not made dependent on the desired size of loops, but are made to come within the foregoing determined limits which are changed to arrive at a suitable rolling speed and length of loop. The numerical example will make this clear.

Determining Delivery Speed

What exit speed, a_{19} , is necessary in the oval pass No. 19 to give the theoretical length of loop s_{th} between passes 19 and 20 when the wire length is 114.8 feet?

Ordinarily where l_x is the wire length of the pass x ; t_x , the pass time; a_x , its exit; e_{x+1} , the entrance speed of the following pass; and s_{th} , the theoretical secondary loop length between the passes x and $x+1$, the relation $(l_x \div a_x) = t_x$ holds because the rolling speed multiplied by the time is equal to the length of wire rolled. Moreover, $t_x (a_x - e_{x+1}) = s_{th}$ because the amount which the roll, x , brings is more than the roll, $x+1$, takes away and this goes into the loop.

$$\text{Thence: } \frac{l_x}{a_x} (a_x - e_{x+1}) = s_{th}$$

$$l_x - l_x \cdot \frac{e_{x+1}}{a_x} = s_{th}$$

$$a_x (l_x - s_{th}) = l_x e_{x+1}$$

$$\text{Thence: } a_x = e_{x+1} \cdot \frac{1}{1 - \frac{s_{th}}{l_x}}$$

With this last formula in Table V, the exit speed of the previous is calculated from the entrance speed of the following pass.

If we call the reduction in per cent A , the elongation

a_x , as was shown previously equals $e_x n$. Therefore,

$$e_x \frac{1}{1 - \frac{A}{100}}$$

This substituted in the foregoing equation for a_x , gives

$$e_x \frac{1}{1 - \frac{A}{100}} = e_x + 1 \frac{1}{1 - \frac{s_{th}}{l_x}}$$

Consequently, then $e_x = e_x + 1$, if $A = \frac{s_{th}}{l_x} 100$.

In other words the entrance and exit, or, roll or circumference speeds of two rolls then become equal, if as large a percentage of the wire length goes into the loop, as amounts to the reduction between the two passes. It means, that with two rolls having equal diameters and revolutions per minute as much wire goes into the secondary loop during its passage through the first roll, as the reduction amounts to in the second roll. Or, if all over a size of loop corresponding to the reduction is permitted, all stands would have equal rolling speeds, therefore, equal diameters and revolutions per minute. Or thirdly, the circumference speed must be diminished. Consequently, with the same revolutions per minute the diameter of the previous roll, in the same relation as the percentage size of the loop, should be smaller than the reduction.

Affords Calculation of Loops

According to the foregoing suggestions, the size of the loops can be calculated with a given rolling speed, or, for a given rolling speed and a desired loop, the exit speed in the previous stand can be determined. In addition the roll train can be subdivided into different groups with different revolutions per minute, and the roll diameter stepped inside the groups. A theoretical size of loop, which appears desirable for the different passes, then is included in the table. About 10 per cent of the

wire length is allowed to go into the secondary loops.

Then $\frac{e_{20}}{0.9} = a_{19}$, $e_{19} = \frac{a_{19}}{n_{18}/19}$, $\frac{e_{19}}{0.9} = a_{18}$, etc.

The relation of loop to wire length now will conform to the equation just given for pass No. 20 backwards to No. 9, which in Table VI, are given for the designated entrance speeds e , exit speeds or rolling speeds a , pass times t ($=l/a$) and effective loop lengths $s_{\text{eff}} = t_x (a_x -$

Table VI

Rolling Speeds with a Loop 1-10 the
Wire Length

Pass No...	20	19	18	17	16	15	14	13	12	11	10	9
$e = \dots$	25.6	24.7	21.6	18.0	16.1	12.3	10.2	7.68	5.87	4.43	3.39	2.34
$a = \dots$	28.8	28.3	27.4	23.9	20.0	17.9	13.7	11.3	8.53	6.53	4.92	3.77
t in sec. =	45.5	40.4	36.4	32.3	29.1	26.2	23.7	21.4	19.2	17.3	15.65	13.9
$s_{\text{th}} \dots$	114.8	100.1	74.2	61.7	46.9	32.5	24.3	16.4	11.3	7.71	5.25	
$s_{\text{eff}} \dots$	134.5	119.8	93.8	78.1	66.6	52.2	44.0	36.1	31.0	27.4	24.9	

Table VII

Loop Lengths with Rolling Speed
the Same

Pass No...	20	19	18	17	16	15	14	13	12	11	10	9
$e = \dots$	25.6	24.9	22.6	21.8	23.3	19.7	21.7	19.7	19.7	19.7	19.7	17.7
$a = \dots$	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8
t in sec...	45.5	40	34.6	27	20	16.3	11.3	8.4	5.7	3.9	2.7	1.8
s_{eff} in ft. .	150.9	156.8	188.0	160.8	110.6	123.4	80.9	72.2	55.4	44.3	36.1	

$e_x + 1$ + 19.7. The elongations and wire lengths necessary for the calculation are taken from Table V.

The loop lengths would correspond, but the rolling speeds, a , fall so rapidly that it will be impossible to hold them even in a triple stepped train with three different revolutions per minute without making the difference of the diameters too large. Table VI, therefore, is an example of where the desired loop sizes must be enlarged with respect to what is practically possible,

that is, by the rolling speeds attainable by a two-thirds fold stepping.

In considering the other extreme from the stand-point of the rolling speed, wire trains which have several alternating mills arranged 2-high in a row are taken. These have equal revolutions per minute and equal or approximately equal roll diameters. The table is determined by the same rolling speed, a , in every case and takes the following form: The loop lengths with the rolling speed, a , the same, are presented in Table VII.

Elongation and wire lengths for the calculation are taken from Table V. Between passes Nos. 16, 17, 18, 19 and 20 the loops which are in excess of 134.5 feet assumed. With the first passes from No. 9 to about 17, the rolling speed, 28.8, will be so high that the roller will not be able to catch the piece securely.

The higher rolling speeds are used only where the capacity demands, regardless of the difficulty of catching or the large amount of work consumed running light and the wear of the necks. In a wire mill, as much material must be fed per unit time at one end, as comes out at the other end or in this case as many cubic inches of steel, as the finishing roll turns out per second. The latter amount with four wires of 0.029-square inch cross section and 28.8 feet a second exit speed is $4 \times 28.8 \times 12 \times 0.029 = 40.89$ cubic inches.

Equal Quantity Necessary

The same amount a second must enter in the first roll. If less were to go through, the production would no longer be determined by the finishing roll but by the first stand. If more enters, the excess must be choked down by delays in entering the individual billets. The condition applying to the entering stand of a wire mill also applies for every intermediate stand. The same amount of material should be fed a second, as goes through the finishing roll. If less goes through any stand, the production of the whole train is curtailed. If

more passes go through a stand, the number of pauses in entering the stock is increased. The best practice is to let the particular rolls run slower, because the high revolutions per minute would otherwise consume power and wear the necks. Let us look at the table of figures with the same rolling speeds. Material going through a mill with the rolling speeds the same, amounts to $q \times 28.8$ times the number of wires. Table V shows that 40.866 cubic inches are attained in pass 14. Then $1 \times 28.8 \times 12 \times 0.119 = 41.191$ cubic inches. Pass 13 gives $28.8 \times 12 \times 0.169 = 54.921$ cubic inches. Therefore, the excess speed is:

$$\frac{54.921 - 41.191}{54.921} \times 100 = 25 \text{ per cent}$$

This speed is higher with passes Nos. 12 to 9. Material can be worked with such trains, but they waste power and make the work unnecessarily difficult for the roller.

After considering the working and rolling pauses, from Table V a production of 518,500 cubic inches an hour ($1.178 \times 12.8 \times 12 \times 3600 \times 0.8$) is received for the continuous mill and 117,730 cubic inches an hour ($41 \times 3600 \times 0.8$) for the finishing mill. Instead of equalizing the production of the individual groups by slowing down the continuous mill as stated previously, it can be accomplished by increasing the number of wires passing through the finishing mill or speeding up this mill or both. A third possibility would be to choose a smaller billet and reduce this to a cross section of 0.482×0.482 -inch on the continuous mill (see Table V, line 3, pass 12). In this case group I would not be necessary. To carry out all these possibilities would be beyond the scope of this book. Table V does not represent a pattern for a modern wire mill; moreover, it was based purposely on an incomplete wire pass design in many cases, in order to include all the possible considerations of loop length, revolutions per minute and number of wires.

Where the rolling speed in the last passes is based

on the desired size of loops the corresponding exit speed is obtained from the equation:

$$a_x = e_x + \frac{1}{1 - \frac{s_{th}}{l_x}}$$

Therefore, for pass No. 19 we have

$$e_{20} = \frac{28.8}{1.13} = 25.6$$

$$A_{19} = 25.6 \frac{1}{1 - (95.1 \div 1148.3)} = 27.9 \text{ ft./sec.}$$

$$\text{from this } e_{19} = \frac{27.9}{1.15} = 24.3$$

The rolling speed from pass 17 would be 24.3 feet a second. With u equaling 600 this speed corresponds to a roll diameter of 9.252 inches. The diameter is chosen because of the wear which is assumed as 15 per cent and not over 9.449 inches. This will permit a diameter of 8.071 inches in the worn out state. Consequently, the speed, 24.3, is increased in the relation of $9.449 \div 9.252$ or 24.6. The pass time will change to $756.9 \div 24.6$ or 31.5 seconds and s_{th} to $31.5(24.6 - 21.3) = 103.3$ feet. As smaller diameters are not desired after these four stands, a new group with a lower revolution a minute must be provided with special gearing and separate drive shaft. If between passes Nos. 16 and 17, because of the wire length having become shorter, a secondary loop length of 78.7 is assumed or an actual length of 98.4 feet, then

$$a_{16} = 18.2 \frac{1}{1 - \frac{78.7}{700.8}}$$

which with 11.024 inches diameter requires a roll speed of 440 revolutions a minute.

With the second group the roll diameters are assumed, for illustration, as 11.024, 10.630, 10.236 and

9.843 inches. The rolling speeds are taken as 21.0, 20.3, 19.5 and 18.7 feet a second; the entrance speeds in passes 16 to 13 as 16.7, 14.1, 14.4 and 12.6 feet a second, and the secondary loops as 83.0, 89.8 and 55.4. If another subdivision is required, that is, a third group with a lower speed, the rolls in pass No. 12 should be 9.449 inches diameter, the speed from there down being:

$$\frac{9.449 \times \pi \times 440}{12 \times 60} = 18.04 \text{ ft./sec.}$$

If this is desirable, the volumes per second passing through the rolls are determined. After calculating the volume $V = m = q \times a$, which would leave each roll a second if only one wire were in the pass, the result is included in the horizontal line No. 14 of Table V. It must be obvious that if the same volume should pass through each stand in the unit of time as goes through the last stand, that is, 40.89 cubic inches a second, that four wires will traverse the rolls side by side in passes Nos. 18 and 19, three in Nos. 16 and 17, and two from there down to pass No. 13. It is advisable to provide an extra pass, Nos. 5, 4, and 3 side by side and equip them with guides. Roll No. 12 with a speed of 440 revolutions a minute, a minimum diameter of 9.449 inches and with one wire a second has 12×18.04 (rolling speed) $\times 0.233$ (cross section) or 50.439 cubic inches a second. This volume is 23 per cent more than is produced by roll No. 20, representing an excess roll speed of about 20 per cent. For roll No. 9, $V = 12 \times 18.04 \times 0.729 = 157.814$ cubic inches or almost four times the amount required.

Such speeds are unnecessary and, consequently, call for further calculation. A possibility would be to include rolls Nos. 12 and 11 in group II with 440 revolutions a minute and to add Nos. 10 and 9 to the continuous rolls. Stand No. 11 then would have a volume a second of $12 \times 18.04 \times 0.310$ or 73.838 cubic inches. To avoid excessive speeds the stock is passed from group I to group II with the smallest possible loop of 42.7 feet effective or

23 feet theoretical. This gives for a_{12} :

$$12.6 - \frac{1}{\frac{23}{164}} = 14.8 \text{ ft./sec.}$$

From this the entrance speed $e_{12} = 14.8 \div 1.45$ or 10.2; $a_{11} = 14.3$; $a_{10} = 14.8$, and $a_9 = 16.4$ feet a second. A speed of 300 revolutions a minute and diameters of 11.220, 10.827, 11.220 and 12.598 inches are assumed. In order not to go up and down, the roll diameter of pass No. 3 is taken as 11.220 and pass No. 1 as 12.598 inches. The speed at pass No. 11 and the loop change between passes Nos. 12 and 11, and Nos. 11 and 10 are given in Table V. In filling in the volume, V , in the horizontal line 16 of Table V, the amount always should be larger than in the finishing pass. The volume with roll No. 15, is 40.28 cubic inches instead of 40.89 cubic inches. An equalization would be possible by increasing the roll diameter to 11.024 inches. If this smaller volume is permitted on one stand, it denotes a choking of the capacity will take place at this point. In other words, the capacity is not determined by the finishing pass of the train, but by pass No. 15. This moderation appears unimportant when the reserve production of the finishing roll is considered.

Therewith the open part of the train is determined. The only point remaining in the example is the unnecessarily high speed of rolls Nos. 13, 10 and 9. The speed cannot be changed unless the reductions are altered. The latter can be avoided by adding rolls Nos. 9 and 10 to the continuous part. Where the volume passing through is larger than in the finishing pass, the stock must be held back correspondingly, so that the wires do not interfere with each other. Roll $x + 1$ is not immediately free, if the end of the wire has left the roll x . This requires pauses between the last mentioned period and the entering of the new wire into x . In this manner a velocity, which is too large, can be regulated.

For every group of the open and for every stand of

the continuous mill separate spindle housings and especially drive shafts are required. These generally are driven in the case of the continuous group through gear transmissions by the same motor. Pitch line diameters and the number of teeth are determined from the exit speeds in Table V if the roll diameters of a group are made the same size. If the transmissions do not work as intended, corrections can be made by turning down the rolls. The final adjustment is accomplished by giving more or less draft in the individual stands. The exit speed of a roll thereby remains the same. The entrance speeds decrease with increasing draft and increase with decreasing draft. Therefore, if the tension of the stock is too strong, the draft in stand No. 2 is increased; if it is too weak causing the stock to twist or pulsate, less draft is given.

Drive Is Optional

The drive shafts of the open mills either can be driven by separate motors, or a single motor. The most efficient arrangement is to install the trains so that the roll planes are close as shown at *A* in Fig. 104 and not stepped in front of one another as shown at *B* in Fig. 104. In the latter case the mills are spread out and it is difficult to loop the straight rod, *a* between trains Nos. 1 and 2. If the rod is subjected to tension, the previously mentioned inaccuracy due to the end not being drawn, extends over a larger part of the finished wire.

Moreover, long pieces increase the cooling. The arrangement shown at *A* in Fig. 104 requires that the jack shaft of train No. 2 does not interfere with train No. 1, and train No. 3 with trains Nos. 1 and 2, so that neither the roller nor the mechanical loop guides are disturbed. This can be accomplished if the shafts are driven through the bottom pinion. This is not recommended because in this case the teeth of the lower pinion receive double-tooth pressure and wear out faster. If the middle roll is driven, the upper edge of the bottom roll

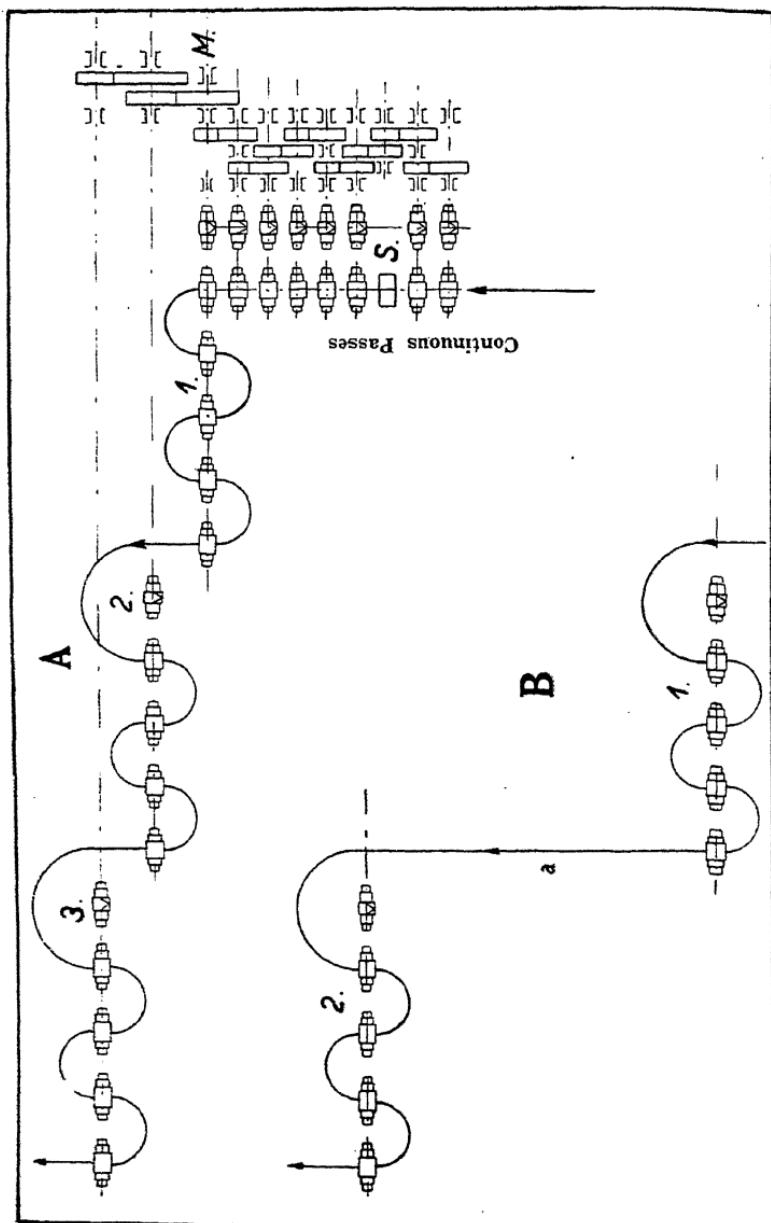


Fig. 104—(A) Arrangement of Three Separate and Open Roll Trains Installed in a Staggered Position.
 (B) Arrangement of Two Open Roll Trains Installed One in Front of the Other

of train No. 2 as shown in Fig. 105 must be set so high, that the floor 1 to 1.3 feet lower, is still higher than the shaft of train No. 3. Therefore, different elevations of the floor for the three trains of rolls are required which is an inconvenient arrangement for a mill layout.

The continuous train often is subdivided, so that between the second and third stands, a shear to cut the billet is installed. The largest billet, which has been used for wire mills to date, according to the knowledge of the author, is 6.299x6.299 inches. The billet can be sheared without bringing it to rest by flying shears, the blade following the movement of the stock.

An efficiency of approximately 10 per cent for the

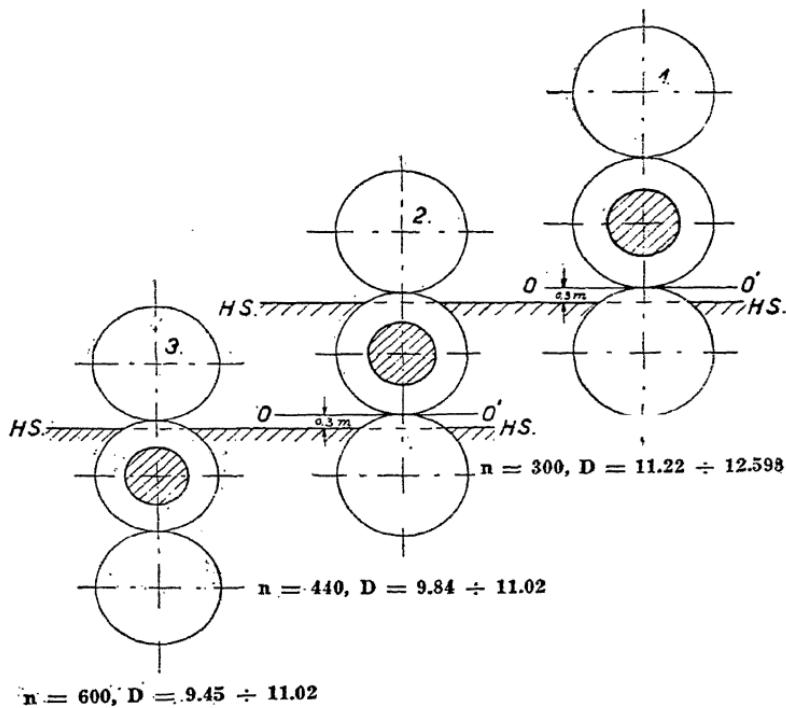


Fig. 105—Elevation of the Roll Trains Shown in Fig. 104

power requirement of wire mills has been determined by H. Meyer. The theoretical energy requirement is $A_{th}=V \times k \times l_n n$ if the elongation is denoted by n , the volume by V in cubic inches and the elastic limit in compression by k which for steel at the rolling temperature is 14,220 pounds a square inch maximum. If in place of the volume the weight in pounds is substituted, G , the relation for 1 ton is $V \times 485 = 2200 \times 1728$. Then, $V = 7811$ cubic inches and $A_{th} = 14,220 \times 7811 \times l_n n = 3.5 l_n n$ kilowatt hours for 1 ton of steel. The different trains produce in each hour considering the working pauses $350 \div (24 \times 0.9)$ or 16.2 tons. The entering pauses distribute themselves uniformly in the total time and, therefore, are included in the number 24. The elongation of train No. 1 of the open mill amounts to $1.178 \div 0.233$ or 5.1; of train No. 2, it amounts to $0.233 \div 0.066$ or 3.5; and of train No. 3 it amounts to $0.066 \div 0.029$ or 2.2.

The natural logarithms of the elongations are 1.63, 1.25 and 0.79 respectively. The required theoretical output therefore amounts to:

$$\begin{aligned} \text{Train No. 1} &= 3.5 \times 1.63 \times 16.2 = 93 \text{ kilowatts} \\ \text{Train No. 2} &= 3.5 \times 1.25 \times 16.2 = 72 \text{ kilowatts} \\ \text{Train No. 3} &= 3.5 \times 0.79 \times 16.2 = 45 \text{ kilowatts} \end{aligned}$$

The effective output therefore is 930, 720 and 450 kilowatts respectively, or a total of 2100 kilowatts. The efficiency of Meyer represents the theoretical available work measured at the switchboard and includes the power consumed during pauses in reduction. It is best to determine separately the power consumed by the mill running empty, otherwise $A_{th}=0$. For the continuous mill $n=34.900 \div 1.179=29.6$ and $l_n n=3.4$. Therefore, $A_{eff}=10 \times 3.5 \times 16.2 \times 3.4=1930$ kilowatt hours. Motors with a total kilowatt capacity, therefore, are required.

If the amount of coal required hourly is to be determined, 20 per cent should be deducted because in the working and rolling pauses no energy is used.

The efficiency of Meyer is more uncertain with wire

mill than with other mills, because with the different sizes of starting billets and with the high bearing friction losses due to the many necks and the high speeds, and, with the small cross sections toward the end of the wire mill, the actual deformation work in comparison to the bearing friction work must be small. In any event the calculations show that the Fink formula for the energy requirement to determine the size of the motors needed for a wire mill give a sufficiently accurate starting point.

One of the oldest roughing pass designs is the gothic pass a diamond with square rolling but with the side arched instead of straight. The gothic in comparison with the diamond has the advantage that the angles are blunter in the corners and therefore cool less. It almost approaches the round cross section in regard to uniform cooling. The arched outline tends to counteract the spread, so that somewhat larger reduction can be given without the danger of serious fin formation.

Gothic Pass Has One Disadvantage

On the contrary a disadvantage is, that the gothic has a greater tendency to fall over, than the diamond shaped or rectangular roughing pass. It requires a profiled rolling course, which is not to be recommended, because the stock is held in the cut-in grooves with difficulty. More recently the gothic pass has been used for automatic continuous mills. If the rolling is done with the square 3-high, the stock is entered in pass *a*, as shown in Fig. 106, goes into *b*, turned 90 degrees and then into *c* and *d* and finally re-entered into *d* to obtain diagonals nearly the same size. Frequently the smaller gothics are put in the upper roll according to passes II and IV in Fig. 107, or the top roll is made to enter the middle roll, as shown by 2 and 4. In this case the order is 1, 2, 3 and 4 and I, II, III and IV respectively. Entering twice in the same pass no longer can be done. The next largest must be used as for example, from III into II or from 4 into 3; and the stock must be entered three

times. The latter alternative denotes lost time and unnecessary cooling while the former does not give exactly equal diameters. The dead pass, however, is used frequently, because it saves 50 per cent of the space. Where space is available, it is advisable to have the top and bottom rolls alike.

A useful construction for gothics is shown in Fig. 108. Geuze advises an arc radius $R=b$ and a rounding off radius of $r=0.1 R$. Kirchberg advises $R=b$, $r=$

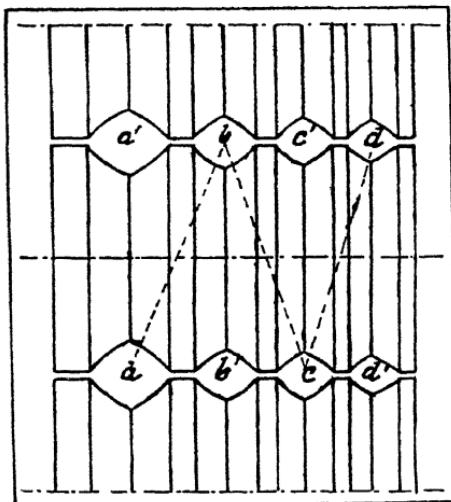


Fig. 106—Types of Gothic Passes

$0.2 h$. Gothics with smaller radii fall over easily. On the contrary arcs with $R=1.5-2b$ frequently are used.

With gothics only the spread is figured, because when the corners, aa' in Fig. 108, are rounded off, the pass is swept sidewise in an arc at B and B' . Every pass, in which these round corners or arcs are not yet drawn, has a spread equal to the height of the previous. It is customary, to express the reduction of the gothic and the diamond roughing pass by a relation of the diagonals. One speaks of $1/7$ or $1/9$ reduction, if the vertical

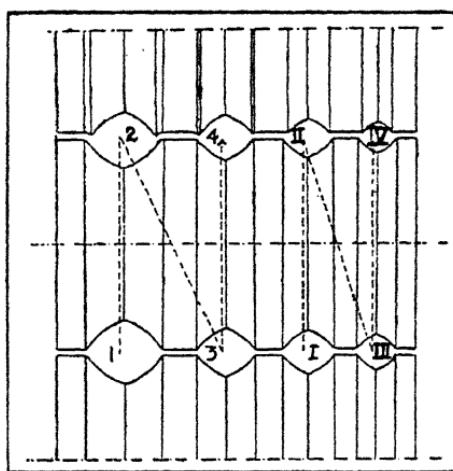


Fig. 107—Gothic Passes in Transposed Position

to the horizontal diagonal of the pass bears the relation of 6:7 or 8:9 respectively. The reduction is then $(6/7)^2$ and $(8/9)^2$ respectively.

The gothic pass is assumed as a surface with straight outlines. Pass I has a height h_1 , and a width b_1 . Pass II has a height of h_2 and a width b_2 . Then,

$$Q_2 = \frac{b_2 \times h_2}{2}$$

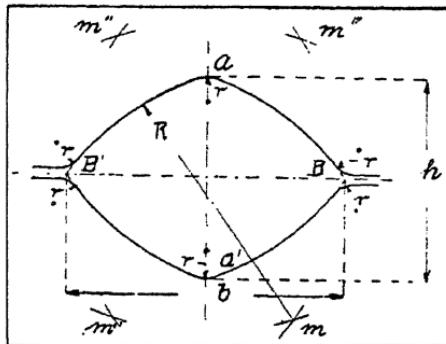


Fig. 108—Construction of the Gothic Pass

$$Q_1 = \frac{b_1 \times h_1}{2}$$

$$A = \frac{Q_2}{Q_1} = \frac{b_2 h_2}{b_1 h_1}$$

$$b_2 = h_1$$

The relation of the diagonals follows:

$$\text{let } \frac{h_1}{b_1} \text{ and } \frac{h_2}{b_2} = y$$

$$A = \frac{h_1 \times h_2}{b_1 \times b_2} = \frac{h_2 \times y}{h_1} = y^2$$

Following are reduction coefficients and limits for springing:

	h/b	A in %	Spring in inches
D up to 1.575"	6/7	0.26	0.118—0.157
D up to 3.937"	7/8	0.23	0.157—0.236
D up to 7.874"	8/9	0.21	0.236—0.396

In the foregoing table, D is understood to be the diameter of the circle inscribed in the pass. It also can be determined with the square calipers as shown in Fig. 109 according to the size designated. Geuze recommends for all passes $1.33D$ as the width of the gothic, and $1.12D$ as the height which corresponds to a reduction of 26 per cent, or of $1/7$. With the larger passes this results in pronounced fin formation. If, however, any effort is made to prevent the fin formation by an increased rounding of the edges, the tendency to fall over is increased.

With gothic passes, a large elongation can not be attained. They are merely preparatory passes. The reduction cannot be too large, because otherwise the stepping will be too large, and a suitable pass on the rougher point of view, the gothic and diamond passes are superior to the flat and elongating passes of a blooming mill. They differ from the latter in that with every pass the cross section closely approximates a square, and roll for each size will not be available. From this which is desirable as a secondary pass for finishing rolls.

With gothics, intermediate cross sections can be rolled by raising or lowering the rolls. With elongation passes or, on the contrary, passes for ingots this cannot be done because by moving the rolls the square shape is lost, and the square no longer will fit the oval and vice versa.

The diamond is a gothic with R indefinitely large. What previously was mentioned about customary elongations, the relation b/h , rounding off radius and spring applies to diamond passes. Only with the spread it is advisable to allow an additional 0.039 to 0.079-inch spread because the straight outlines hinder the spread

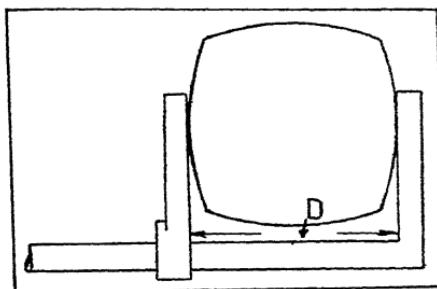


Fig. 109—Determination of the Side of the Gothic Pass

less than the arched. A distinction should be made, therefore, between two horizontal diagonals, the ideal, b_1 , determining the spread and the actual, b_2 , containing the spread.

Where it is not a question of reducing the cross section in definite steps to have a suitable pass on the roughing roll for every size on the finishing roll, but where the sole purpose is to elongate, then alternating square and oval passes, which are the roughing passes of a guide round, are the most suitable roughing passes for about 3.937x3.937 inches down.

The oval and square pass is suitable for pronounced elongation. An oval, which is entered into a square, receives a heavier draft in the center of the profile than

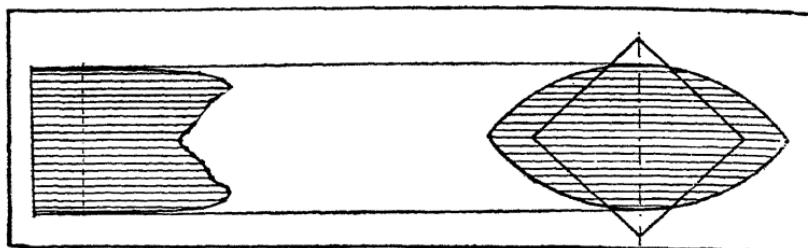


Fig. 110—Elongation Diagram for an Oval Pass into a Square

at the edges as shown in Fig. 110. It is constructed, by making the ordinates at any instant equal the draft at the particular point of the profile, that is, equal to the relation of $h_1:h_2$, and, therefore, to the elongation, which this part of the cross section would assume, if it were independent of its neighboring parts. Thus, the draft from a maximum between the edge and the middle rapidly falls to zero at the edge. The result is, that the edge parts are pulled along by the elongating neighboring parts and shrinkage occurs. The total spread must therefore be small with this rolling process and the elongation correspondingly large. If the elongation in Fig. 110 is compared with the passage of the square through the oval as shown in Fig. 111, the opposite is true. The elongation at the edges is larger than in the center. The edges are held back by the center, therefore, have a strong ten-

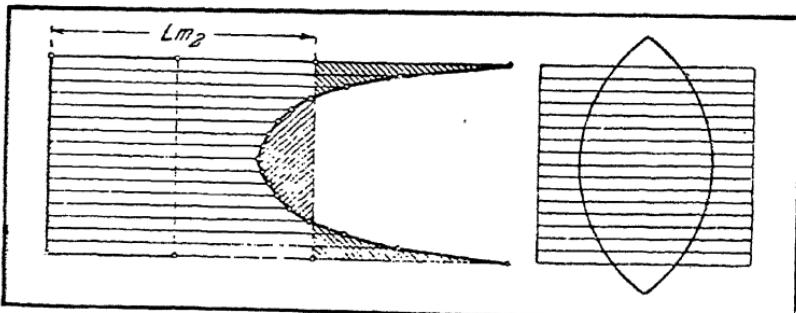


Fig. 111—Elongation Diagram for a Square into an Oval

dency to spread. This is counteracted by the arched outline of the oval. Consequently, it adds to the increase of the elongation, and, with the inner occurrences in the preceding square pass, causes the spread to be small and the elongation to turn out large. In addition the stresses in every pass are large. The stock leaves the rolls stretched straight. The stresses alternate their direction in the next pass and finally equalize themselves in the whole rolling process.

An early construction of the oval from the larger square is shown in Fig. 112, of the square from the

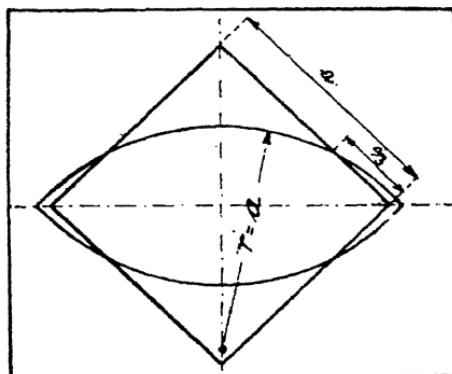


Fig. 112—Construction of an Oval from a Large Square Pass

larger oval in Fig. 113. With the former the radius of the oval is equal to the square side while with the latter the diagonals of the square are equal to two-thirds of the width of the oval. Fig. 112 gives a reduction of 28 per cent and Fig. 113 of 33 per cent. With modern roughing rolls the reduction is considerably higher. A square from 0.787 to 0.984-inch, for example, is reduced from 50 to 55 per cent in the oval pass, and up to 50 per cent from the oval into the square. In the first case the draft of the vertical axis rises to 70 per cent. The rolls still will grip without being roughened.

The reductions are dependent upon the relation b/h of the width to the height of the oval.

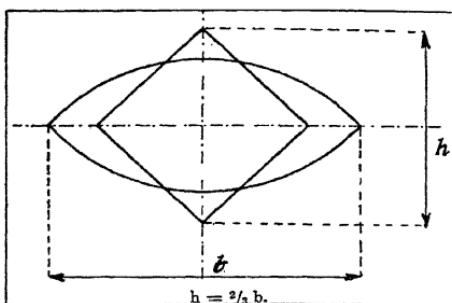


Fig. 113—Construction of a Square from a Large Oval Pass

In the previous edition of this book, considerably smaller reductions were given for the relations $b/h=3$ and 3.5. They were taken from practical pass designs. In the meantime these relations were checked on wire mills and in the rolling mill institute of the Technische Hochschule, Breslau and it was found that the previously mentioned reductions gave passes, which did not fill. If the ovals are to fill, then the reductions as stated must be chosen, in which the lower values are for large, the higher values for small ovals. The pronounced variation in values result from the fact that the roughing work is carried out with elongating passes which fill differently, therefore, with different reductions. In other words, many different sizes of squares can be entered into the same oval. The singular shape of the oval has a kind of automatic regulating effect. With the constructions in Figs. 112 and 113 we have:

Relation	Reduction equals or approaches	Elonga- tion
$b/h =$ or approaches 2.2	30%	1.43
$b/h = 3$	55 to 60%	2.2 to 2.5
$b/h = 3.5$	60 to 65%	2.5 to 2.8

With squares larger than 0.084-inch, it is advisable with the larger masses to be displaced, to use a reduction smaller than 50 per cent. The same applies for squares under 0.787-inch because with this smaller cross section the stock already is colder, and the plasticity is less.

Good pass designs of high-speed roughing rolls are obtained if a reduction ranging from 50 to 60 per cent is chosen with 0.787-inch to 1.278 square inches but above and below this to gradually let it go back to 40 to 50 per cent. Sufficient spread must be allowed, either by estimating or by using Geuze's rule, which for the square and oval, is entirely hypothetical. A spreading surface is equal to 0.35 times the displaced surface as shown in Fig. 114. (0.35 for steel, 0.48 for wrought iron.)

Finally it should be determined if the vertical axis at any place receives more than 70 per cent draft. In Fig. 114, $(H_2 \div H_1) \times 100$ equals or approaches 30.

A. Brovot gives as a rule a relation $b/h=3$. If h is the height of the oval, which is to be entered into a square of the side a , then Brovot recommends that $a=1.2h$ for large profiles and $1.3h$ for small. The width of the oval following the square should be equal to $1.6a$ for large profiles, and $1.9a$ with small profiles, according to Brovot.

The important point is the elongation to be given. It, therefore, is better to use this as the basis, than to proceed according to recipes, because it can be obtained with round as well as slender ovals. The latter give a

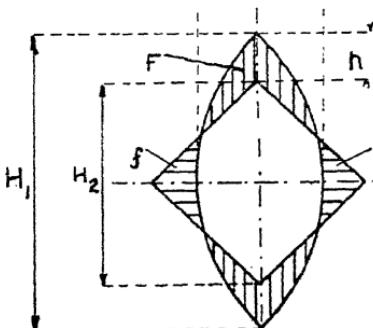


Fig. 114—Spread of an Oval According to Geuze's Rule

larger pass spread, and actually spread more than the round with small b/h , whose arching prevents the iron from moving sideward. This automatic regulation of the spread within certain limits may be the reason for the variable shape elongating passes used in practice. It is in the main empirical, being determined by cut and try methods.

Procedure for Designing Roughing Roll

For example, suppose a high-speed roughing roll is to be designed for a maximum section of 2.756x2.756 inches, a smallest and a minimum section of 0.394x0.394-inch. The latter gives a cross section of 0.155-square inch. An elongation of 1.5 from the previous oval gives for this a cross section of 0.233-square inch and for the next largest square pass 0.349-square inch which is equal to a side length of 0.591-inch. If an elongation of 1.7 is used, the next largest profile, which is an oval with 0.589-square inch and a square with 1 square inch, equals or approaches 1 inch length of side. This gives a profile size, with which an elongation equal to 2.5 is permissible; but to remain with the present stepping, the maximum elongation should be 1.9. This gives for the next oval 1.899 square inches. For the square an elongation of 1.7 is used to obtain 3.224 square inches which is equal to a side length of about 1.811 inches. Finally for the last pass the elongation is 1.5. This gives a next higher oval of 4.836 square inches and a square cross section of 7.254 square inches which is equal to a square of about a 2.677-inch side. The exit billet is 2.756x2.756 inches or 7.595 square inches. To be on the safe side the 0.341-square inch which still is to be displaced over two passes is divided and, therefore, raises the oval cross section from 4.836 to 5.007 square inches.

If the exit billet had been 2.362 inches or 2.150 inches, the elongation coefficients would be increased or decreased so that one would receive a cross section of 5.580 and 9.920 square inches respectively. Or in the latter case if elongations of about 1.5, 1.7, 1.9, 1.7, 1.7

or of 1.6, 1.8, 2, 1.8, 1.6 did not suffice, a square and an oval would have to be added to each. The increase of the elongation of 1.5 in the large cross sections from 1.6 to 1.7 would be desirable. A systematic comparison between the desired and permissible quantities leads to the goal more advantageously than formulae or constructions.

If the area is assumed to approach a parabolic surface, and the relations b/h equals 3, 3.2, 3.4 and 3, the ovals between squares then are determined as follows:

0.394" and 0.590" $Q = 0.233^{1/2} = (b \times b/3 \times 2) \div 3$ or $b = 1.024, h = 0.343$
 0.590" and 0.984" $Q = 0.589^{1/2} = (b \times b/3.2 \times 2) \div 3$ or $b = 1.634, h = 0.512$
 0.984" and 1.811" $Q = 1.899^{1/2} = (b \times b/3.4 \times 2) \div 3$ or $b = 3.110, h = 0.913$
 1.811" and 2.756" $Q = 5.007^{1/2} = (b \times b/3 \times 2) \div 3$ or $b = 4.744, h = 1.875$

With the height and width, three points are given for each half of the oval and, therefore, the arc bounding them.

If the draft in the center of the square profile does not exceed 70 per cent, the test shows that the diagonals of the square equal 1.41 times the square side. The draft in the center for a square is

$$\begin{aligned} 0.394" &= (1.024 - 1.41 \times 0.394) \div 1.024 = 46\% \\ 0.591" &= (1.634 - 1.41 \times 0.591) \div 1.634 = 49\% \\ 0.984" &= (3.110 - 1.41 \times 0.984) \div 3.110 = 55\% \\ 1.811" &= (4.744 - 1.41 \times 1.811) \div 4.744 = 46\% \end{aligned}$$

It is well to check by Geuze's method to make certain that the pass has sufficient spread. If not, the width of the oval must be corrected or the square enlarged somewhat. The error is smaller if the spread is assumed too large rather than too small; in the first case flat ovals or squares result which are somewhat underfilled; in the latter case fin formation results which leads to laminations, flaws or other defects, or, if the fin is rolled in, the quality is impaired.

To set the section of the circle equal to the parabolic surface ($=2/3 bh$) is permissible only in approximate calculations. For accurate calculations the area of the circular section either must be determined as half the surface of the oval or by using the following approximate formula, presented in *Chemikerzeitung*, May, 5,

1925, an accuracy of a few tenths per cent can be obtained:

$$F = \frac{4}{3} \times 0.5 b \times h \left\{ 1 + 0.2 \left(\frac{h}{0.56} \right)^2 - 0.02 \left(\frac{h}{0.56} \right)^4 \right\}$$

Elongation passes often find use with continuous roughing rolls. The individual passes lie in front of one another on different short rolls, which turn with increasing speeds. The stock is led from one to another by stripper and tubular guides, which lie between the rolls and twist the stock 45 or 90 degrees. It is difficult to fit the circumference speed of a roll exactly to the speed with which the stock leaves the previous roll or vice versa because the circumference speed remains constant, while the exit speed depends on the temperature, water cooling etc., and, therefore, is constantly subjected to small changes. If a certain excess of the circumference speed is permitted, the stock is drawn between the stands. This means an increase of the slip between the rolls. The power used for drawing is changed into deformation work. The difficulties of the continuous rolling mill are overcome essentially, in that individual motors whose speed can be controlled, are used for each stand.

Another disadvantage is that the arrangement is cumbersome, difficult and time consuming, and the ends do not have exact dimensions. This is due to the fact that the stock loses width as a result of drawing between the rolls. The ends are not subjected to the drawing between the roll stands, and therefore have a different width than the rest of the rod, which is drawn between all stands of a continuous mill. The roll wear also is increased.

The advantages of this type mill include the saving of all hand work in rolling, which is counterbalanced many times over by the work of adjusting; and the use of shorter and lighter rolls. The longer the body of the roll, the larger the diameter must be. Small diameter rolls do not spread the stock to any large extent but elongate it considerably. This diminution of the spread

and increase of the elongation work is further increased artificially by the drawing action.

Continuous roughing rolls are recommended where large tonnages of same section are to be delivered from the finishing rolls. Instead of the oval pass for large cross sections, flat or trapezoid shapes shown at *A* and *B* in Fig. 116 are used. In the former case they are pinched in the center, as shown at *C* in Fig. 116, to reduce the spread. With the flat pass shapes several can be arranged behind one another, thus obviating the necessity of turning the stock 90 degrees after each pass. The shapes shown in Fig. 117 also are advisable as early passes. Between II and III the stock is turned 90 degrees. Here

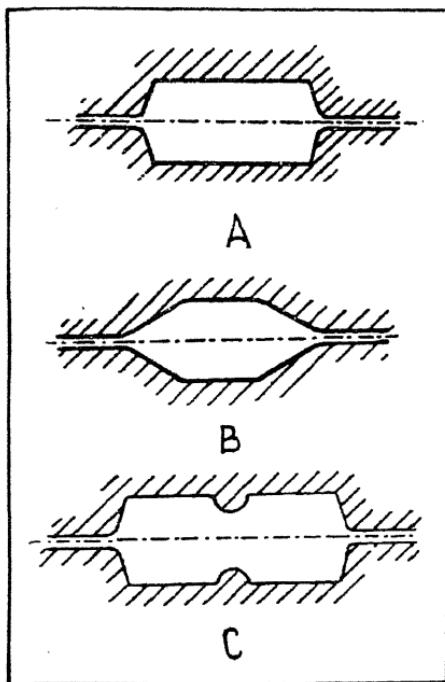


Fig. 116—(A) Diagram of Flat Elongating Pass. (B) Diagram of Trapezoid-Shaped Elongating Pass. (C) Diagram of Recessed Flat Pass

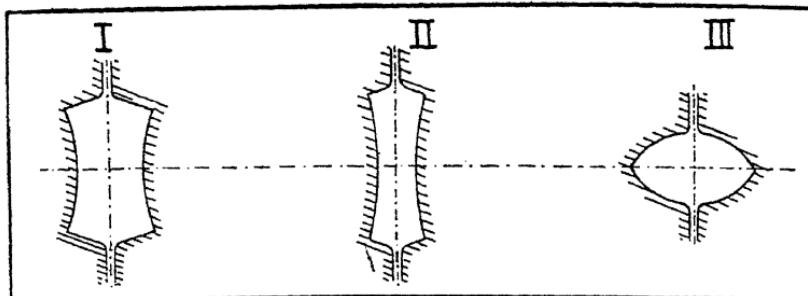


Fig. 117—Continuous Roughing Passes Which Are Advisable During the Early Stages of Reduction

the arched contraction of the upper and lower outlines causes a diminution of the spread by increased elongation of the center, which causes the outside parts to shrink.

Blooming passes are of the open or box type. The box passes are either bounded above and below by parallels or they have a depression as shown at *A* in Fig. 118, in which dimension, *s*, usually is from 0.315 to 0.394-inch according to the size of the pass. They are used mostly in the first three passes. The object of the depression is to prevent fin formation at the depressed part after turning up and to lessen the impact when the rolls grip the piece. The reason for the latter effect is, that with the parallel surfaces indicated by the dotted lines at *A* in Fig. 118 the ingot is gripped simultaneously over the whole upper and lower surface of the rolls, which results in an impact; while with the depressed passes the rolls first grip where the diameters *D* are largest. Until the whole surface and the smaller diameter, *d*, grips, the ingot must have passed through the distance *s*, as shown at *B* in Fig. 118. Finally the depression also diminishes the spread somewhat, because the central pressed part of the stock pulls along the outer part. On the other hand the slip, which the difference in diameters *D* and *d* must occasion, causes a somewhat increased use of power.

The taper is chosen from 4 to 10 per cent. A large taper is more advantageous, because the ingot is more easily released from the pass if too much draft should be given. On the other hand a large taper requires room in the length; therefore where this is scarce, space can be saved by using smaller tapers.

In the parting of the pass as well as in its corners the sharp corners are rounded off. If the radius of the former is r , the radius of the latter R and the draft h_1 and h_2 , then make:

$$r \text{ about } = 0.25 \text{ to } 0.3 \times (h_1 - h_2)$$

$$R \text{ about } = 0.5 \times (h_1 - h_2)$$

With different values for $h_1 - h_2$, the larger draft should be used.

The proper ingot size for the blooming roll, depends on the weight of the charge; the number of sets of ingots which are to be poured from each charge; and on the height of the ingots, which is limited by the consideration of their stability and the size of the available heating furnaces. The desire to eliminate cavities in the ingot by making the material more dense and pressing in displaced material, leads to the choice of the largest ingot

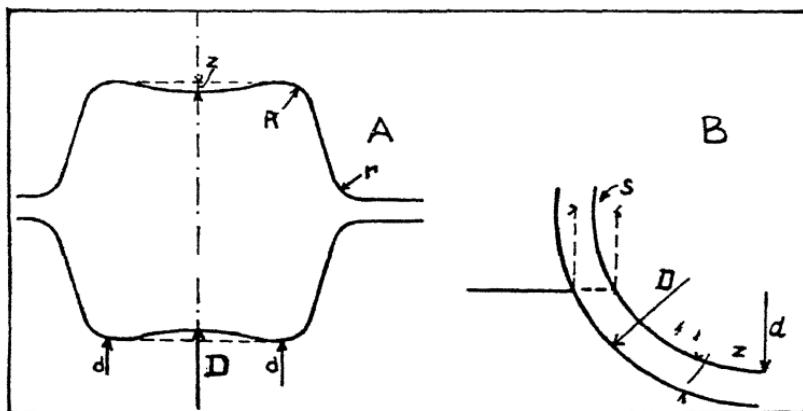


Fig. 118—(A) Diagram of a Box Pass for Blooming Mill Rolls.
(B) Effect of Recessed Rolls on the Upper Edge of an Ingot

cross sections possible. With increasing cross section the tendency to form such cavities increases. It is better to pour dense ingots in the steelworks, than to attempt to make porous ingots dense by rolling. The rolling mill crew is only interested in ingots with too large a cross section, which necessitates the use of considerable power, where the blooming mill must turn out a large output. On the other hand, where the production is limited by orders or for other reasons, taking the power required into consideration the ingot weight should not be chosen larger than is necessary to obtain the production in question. Costs in steel plant in reference to the blooming mill should be determined for this minimum weight. (The determination of power requirements is covered in a later chapter.) Accordingly the costs are calculated with ingot sizes increasing in 200 pound steps, for large ingots in 1000 pound steps and then choose the ingot size giving the minimum total cost. The question of correct ingot size is of vital importance to steel plant costs. With careful deoxidation and degasification, a reduction of the cross section of 10:1 to 15:1 from the ingot to the finished product from the point of condensation of the material ordinarily can be considered as sufficient.

How Rolls Are Arranged and Driven

Blooming mill rolls are arranged as 3-high and reversing 2-high. The method of driving is important. From the standpoint of the first cost and the efficiency of the power plant the flywheel drive is superior to the reversing drive but without the flywheel the 3-high is superior to the reversing 2-high. From the standpoint of rolling, at least with the larger blooming trains, the reversing 2-high is preferred to the 3-high because tilting tables are not required to raise and lower the ingots. In addition the average roll diameter is smaller with equal gripping properties and equal strength.

As the speed of the reversing motors can be varied

the rolling can be started slowly which results in impact-free gripping. The output of the mill is approximately constant for all passes, while in the 3-high with the reduction remaining the same it decreases from pass to pass. Due to the higher speeds in the later passes the reversing 2-high gives the largest possible production. With the 3-high it is difficult to make the top and bottom rolls adjustable so that the steel can only be entered once in each pass. For the same cross-sectional reduction more passes and, consequently, longer roll bodies are needed. For the same reduction, shorter rolls with the same diameter and strength as weaker rolls can be used with the adjustable 2-high mill. The weaker rolls have the essential advantage that the work lost due to spread is decreased. The efficiency of the rolling process, therefore, is increased and the desired reduction achieved in less time.

Small Adjustments Are Made

The disadvantage of the reversing blooming mill with repeated use of the pass is only equalized in a small way by a cheaper roll storage. The adjustment must be somewhat smaller than the greater difference in the dimensions of the ingots to be rolled in the same pass. Assuming the largest ingot to be 19.685x19.685 inches and pressed to 17.717 inches in the first pass and the smallest ingot leaving the same pass to be 12.205 inches, the top roll must be adjustable to more than 7.480 inches. According to American practice the adjustment ranges from 27.559 to 39.370 inches according to the size of the rolls to permit dismantling the rolls without removing the upper bearing blocks from the housings.

The permissible reduction, which usually is expressed by the percentage draft with ingots, depends on the available power, the gripping property and the strength of the rolls. Assuming sufficient power, the allowable reduction increases with increasing roll diam-

eter because this increases the strength as well as the ability to grip. The reduction seldom exceeds 25 per cent with large material and 30 per cent with small ingot cross sections of commercial quality. In the last pass, as far as the rolling of the billets is concerned, it is advisable to use draft from 10 to 20 per cent so that the dimensions will be uniform.

Whether conditions permit such large drafts, depends on the choice of the roll diameter for a definite draft with respect to the gripping of the rolls and to the

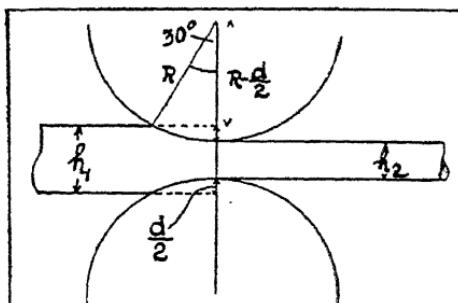


Fig. 119—Ability of a Roll to Grip Depends on Gripping Angle

strength of the rolls. According to Hirst a pair of rolls grip if the angle of grip is smaller than 30 degrees. For example, as shown in Fig. 119 $[R - (d \div 2)] \div R = \cosine 30 \text{ degrees} = 0.866$ ($d = h_1 + h_2 = \text{draft}$). Therefore, $D_a = 2R = d \div 0.134 = \text{or approaches } 8d$.

If the gripping angle given by Geuze of $22\frac{1}{2}$ degrees is used D_a equals or approaches $13d$. Therefore, for the roll to grip, its working diameter at least must be eight times larger than the draft, which is based on the incompletely correct assumptions, that half the draft goes to the upper and half to the lower roll. That the ability to grip is dependent on other matters was pointed out in Chapter II. The per cent draft in $1/100$ parts of E is $d = (E \div 100) \times h_1 = D_a \div 8$. Therefore, $D_a = E \div 12.5 \times h_1$. This gives with 25 per cent draft, $D_a = 2h_1$; with 20 per

cent draft, $1.6h_1$; with 15 per cent draft, $1.2h_1$, and with 10 per cent draft, $0.8h_1$. Therefore, the larger the draft, the larger must be the working diameter with a blooming pass in relation to the height of the stock if the roll should grip.

Rolls and roll housings should be designed according to the principle of equal strength. The bodies should

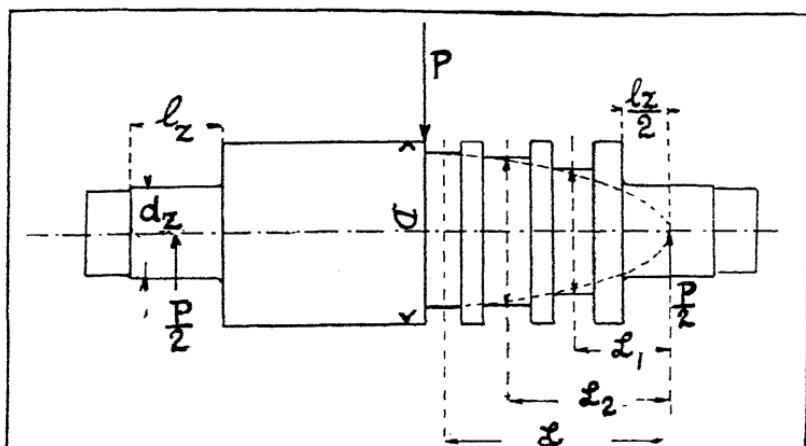


Fig. 120—Roll Design in Which the Body Has the Same Strength as the Necks

have the same strength as the neck but the housings should be larger. Both must resist the force, $P/2$ which from Fig. 120 equals $(3.1416d^3_z \times k_b) \div (32 \times l_z) = (3.1416 D^3_1 \times k_b) \div (32 \times L_1) = (3.1416 D^3_2 \times k_b) \div (32 \times L_2)$, etc. This gives a parabola for the curve to which the passes may be cut into the body, as shown in Fig. 120.

Ordinarily the diameter in the center can be determined and the passes arranged with increasing depth toward the edge. If the resultant diameter is larger than desired, the body length must be shortened. Diameters larger than 43.307 inches are seldom used for blooming rolls. The demand of equal strength is fulfilled approximately by the rule that the deepest pass at the edge and with the largest wear should not be weaker than the

neck. In most rolls the relations set up for gripping will give sufficient strength.

If the power requirement, A , for the pass in question is the work expended in foot pounds; U , the force necessary for the rolling process effective at the circumference of the rolls in foot pounds; and, l the length of the ingot after the pass, then U , which equals $A \div l$, is known for each pass as soon as A is calculated. If U is drawn as the ordinate and l as the abscissa in a diagram, the work performed in each pass, as shown in Fig. 121, may be designated as the surface F_1 , F_2 , F_3 , etc. If the train

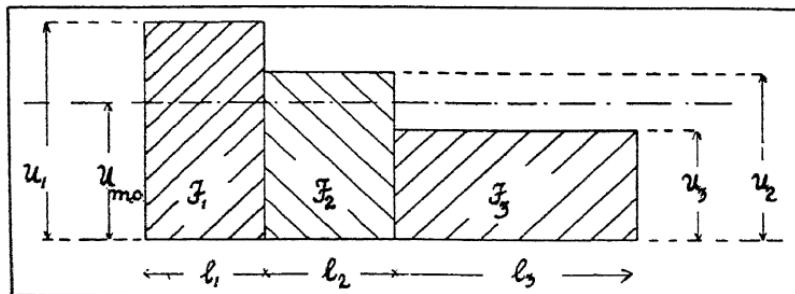


Fig. 121—Roll Section Showing the Work Performed in Each Pass

has equal speed, as in the case with the 3-high driven by a flywheel engine, the times t_1 , t_2 , t_3 , required for the piece to go through the pass are related on one another as the lengths l_1 , l_2 , l_3 . The rolling is determined from the volume of the stock, the elastic limit in compression and the elongation. If the latter is assumed equal for every pass (often the case) and for the elastic limit in compression (also approximately true as long as the rolling temperature remains about the same), the same amount of rolling is necessary for every pass, because the volume of the ingot also remains constant. In pass two the rolling takes longer than in pass one and longer in pass three than in pass two. The longer the time required for a certain work, the smaller the efficiency.

From this it is clear that with the reduction and

equal rolling speed, the efficiency is lower with decreasing pass-section, or in the same amount as U , as shown in Fig. 121. The efficiency and the circumference force are proportional when the rolling speed remains the same. The engine and train, therefore, are used less efficiently with continued reduction in section.

This is different with a reversing engine without a flywheel, where the speed varies from 0 to a maximum. In this case the rolling speed, V , can be increased in the same amount as the circumference force decreases as

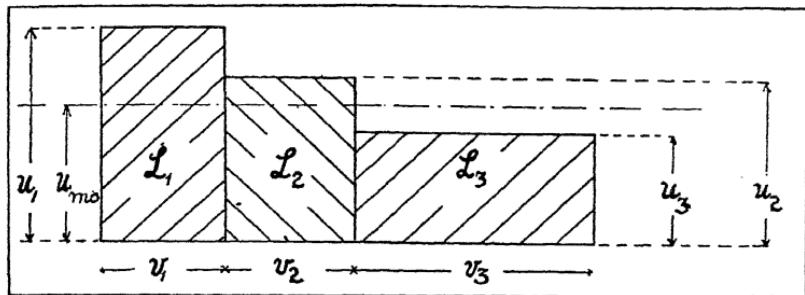


Fig. 122—Roll Section Showing the Rolling Speed in Each Pass with Constant Output

shown in Fig. 122 and receive constant efficiency. The work in the time unit is equal to the effective force, U , times the path through which it acts in the time unit, therefore times the rolling speed or $L = U \times v$.

If in Fig. 122 L_1 , L_2 , L_3 are assumed as equal perhaps to the maximum efficiency L of the primary engine of a transformer, v_1 , v_2 , v_3 , etc., will be given as $L \div U_1$, $L \div U_2$, $L \div U_3$ as U_1 , U_2 , U_3 and v_1 , v_2 , v_3 , etc., are given by the formula $A = U \times l$. The proper rolling speed need not first be determined because it results automatically as long as the engine gives the mentioned output. With decreasing ingot cross section the rolling speed becomes faster and faster.

The diagrams in Figs. 120 and 122 can be used to match the drafts in the individual passes to the avail-

able engine power. For this purpose the efficiency equation used is $L = (U_{\text{mean}} \times n \times 3.1416 \times D) \div (60 \times 550) = (U_{\text{mean}} \times v) \div 500$. The circumference force is U_{mean} in regard to the average roll diameter D in feet which the motor is capable of delivering. v is the rolling speed in feet per second, n the speed of the train and L the capacity of the engine in horsepower. The value for U_{mean} and for the circumference forces U_1 , U_2 , U_3 , etc., occurring in the individual passes are incorporated in the diagram which can be calculated from A and l_1 , l_2 , l_3 , etc.; and with equal drafts from $A_1 \div l_1$, $A_2 \div l_2$, $A_3 \div l_3$. For its determination drafts of about 15 per cent for the first two must be assumed, 20 per cent for the two following and 25 per cent for the remaining passes. If the values of U_1 , U_2 , U_3 , etc., remain under U_{mean} the assumed drafts can be retained. If they exceed U_{mean} the draft in those passes must be modified for otherwise the engine would be stalled. The modification of the draft should be such that the newly calculated U_1 , U_2 , etc., are somewhat lower than U_{mean} .

The foregoing applies for engines without flywheels. If a flywheel is used the degree of inequality, d_s , must be decided in regard to the quotient, that is, the largest minus the smallest divided by the average speed or, $d_s = (v_{\text{max}} - v_{\text{min}}) \div v_{\text{av}}$. For blooming mills d_s can be taken as one-fifth. From this the work expended by the flywheel is obtained, in that its speed is diminished by 20 per cent in foot pounds. Therefore, $A_s = (mv^2 \times d_s) \div 0.9$, where m is the mass of the flywheel circumference, d_s the degree of inequality, v the circumference speed in feet per second. From this equation the circumference force U_s results which is to be added to U_{mean} .

Calculating the Force

An example of the foregoing description follows. The theoretical work requirement of the first pass of a blooming roll with 15 per cent draft amounts to 506,310 foot pounds. After the first pass the length will be 6.562

feet, the rolling speed is 4.921 feet per second and the roll diameter 3.281 feet. The mill is driven by a 1000-horsepower motor. The circumference force expected from the motor with relation to the roll diameter, according to the foregoing equation, amounts to: $1000 = (U_{\text{mean}} \times 4.921) \div 550$. Therefore, $U_{\text{mean}} = (1000 \times 550) \div 4.291$ or 110,000 pounds. With a roll train efficiency of about 50 per cent, according to the evaluation of the Puppe tests made by the author, the effective power requirement equals $2 \times 506,310$ or 1,012,620 foot pounds. To produce this on an ingot 6.562 feet long, a circumference force $U_i = 1,012,620 \div 6.562$ or 154,000 pounds is necessary while only 110,000 pounds is available. The motor, therefore, would be stalled in the first pass with 15 per cent draft if a flywheel was not used.

Checking the Performance

Whether the motor will perform without the aid of the flywheel can be determined according to the following example. The circumference force of 154,000 pounds moderates itself as the natural logarithm of the elongation. According to the following,

Draft per cent	Elongation $\frac{100}{100-d}$	Nat. Log. of n	Circumference force, lbs.
15	1.18	0.17	154,000
12.5	1.14	0.14	127,600
10	1.11	0.11	99,000
7.5	1.08	0.08	72,600

the draft permissible by the available motor capacity, therefore, lies between 10 and $12\frac{1}{2}$. To remain below, 10 per cent is chosen. With passes Nos. II and III the procedure is the same until one with its circumference force lying below that of the motor is received. The remaining smaller passes need not be investigated.

Whether a flywheel of 19.685 feet diameter and weighing 20 tons would supply the missing circumference force of 154,000 — 110,000 or 44,000 pounds with 15 per cent draft is determined as follows.

With d_1 equal to one-fifth the retarding work, A_1 ,

equals $(mv^2 \times d_s) \div 0.9$. For the determination of v , the speed of the train with a rolling speed of 4.921 feet per second must be calculated. Since the roll diameter equals 3.281 feet it amounts to $z = (60 \times 4.291) \div (3.281 \times 3.1416)$ or 29 revolutions a minute. From this $v = (z \times 3.1416 \times D) \div 60$ or $(29 \times 3.1416 \times 19.685) \div 60$ or 29.528 feet. The mass, m , is $44,000 \div 32.2$ or 1370; $d_s = 1/5$ or 0.2. Therefore, $A_s = [1370 \times (29.528)^2] \div 0.9$ or 267,620 foot pounds. This is the work which must be given up by the flywheel over a path equal to 6.562 feet, the length of the ingot after the pass. The circumference force, U_s , with which it works on the ingot, is 267,620 \div 6.562 or 40,700. This force is insufficient to pull the ingot through the rolls. It, therefore, would be necessary to have a flywheel weighing $(20 \times 44,000) \div 40,700$ or 22 tons.

Different Drafts Are Used

In the 3-high mill an overdraft from 0.315 to 0.591-inch is given purposely to be certain that the ingot is pressed against the guide and to prevent it from rising. In the 2-high mostly underdraft is given. The heavy ingots which are rolled there, are prevented from rising due to their weight; the underdraft diminishes the load on the rollers. To use the dead passes of the 3-high mill, the same pass is not cut so deeply into the upper roll as into the lower in order to give the ingot draft. The overdraft often is increased to 1.969 inches and more and while this consumes power it affords the saving of space in the case of the 3-high mill.

The original and final cross section of the ingot generally are square. The draft, therefore, cannot always be in the same direction because the ingot would have the shape of a pressed rectangle. In blooming, the stock is edged by turning 90 degrees at intervals.

As a rule tilting fingers are installed on one side of the rolls but if placed on both sides, a reserve is provided in case of a breakdown. In the design of

passes, therefore, provision should be made for tilting on one side of the mill or the other or on both sides. The pass design and the layout of the roll depend on which method is followed; and, how far the blooming mill rolls must reduce the cross section, and from whereon it serves only as a preparatory roll to deliver bloomed material of definite, mostly square, cross section.

Energy Depends Upon Draft

Fink has proven mathematically and Kiesselbach has determined from the Puppe tests that the specific power requirement, that is, the energy requirement per ton of elongated material becomes smaller the larger the draft is chosen. Inside the previous standing limits of strength, ability to grip, capacity of machinery and material, a draft ranging from 25 to 30 per cent would be chosen.

With ingot cross sections of 7.87 square inches and larger these limits with the mentioned drafts frequently are exceeded in case large engine and roll dimensions are not used.

Assuming the drafts for the various passes are suitable as regards the ability to grip, strength and engine capacity, the ingot is pressed in a 3-high mill in adjacent passes lying above one another (in adjustable 2-high mill partly in the same passes, partly in the adjacent box passes, or in the flat pass), until the relation of width to height has increased from 1.2 to 1.5 (1.4 to 1.5 with ingots of 3.937 to 7.874 square inches and 1.2 to 1.3 with ingots 19.685 square inches and larger). The section is turned and edged to remove the spread which the ingot experienced in the flat drafts. Hereafter several flat passes are made, etc.

The permissible draft will be 15 per cent for an ingot 11.811x11.811 inches, 20 per cent for an ingot 7.874x7.874 inches and 25 per cent for smaller cross sections. The draft of the last pass when producing billets should be about 10 per cent. The tilting fingers should be installed on the exit side of the mill. The

Table VIII
Stages of Reduction for 11.811" Square Ingots

No. of passage	Draft per cent	Ingot dimensions after the pass, inches	$\frac{b}{h}$	No. of the pass	Exit
1	15	10.039 x 12.402*	1.25‡	I	rear
2	15	10.630 x 10.630*			front
3	15	*11.142 x 9.055*	1.25‡		rear
4	15	*9.449 x 9.506			front
5	15	*8.071 x 10.079*	1.30‡		rear
6	15	8.593 x 8.543*		II	front
7	15	*9.016 x 7.284*	1.24‡		rear
8	20	*7.244 x 7.874			front
9	20	*5.748 x 8.346*	1.45†		rear
10	20	6.299 x 6.693*		III	front
11	20	*6.732 x 5.354*	1.25†		rear
12	20	*5.354 x 5.827		IV	front
13	22.5	*4.134 x 6.260*	1.50†		rear
14	25	4.646 x 4.724*		V	front
15	25	5.039 x 3.543*	1.45†		rear
16	15	*4.291 x 3.780			front
17	10	*3.898 x 3.898			rear

*Dimensions which receive draft.

†Stock is tilted.

‡Stock is tilted although the tilting can be delayed one pass without b/h being too large.

smallest cross section should be about 3.937 inches square. The spread amounts to one-third of the draft. Other details are presented in Table VIII. In passages No. 3 and 4 the drafts are mediated slightly so that the rolls do not have to be raised. In the case of steel rolls the inner collars are made to equal one-half the pass depth while the outer collars are chosen so that a heavy guide has room between the stand and the edge pass.

V

SHAPES REQUIRING EQUAL AND UNEQUAL DRAFT

ROD, flat, hoop, round and square profiles often are designated as merchant bars, because they represent the principal raw material of steel consumers. Profiles, such as angles, tees, I-beams, etc., as well as numerous types of special profiles, including sash bars, half rounds, railing profiles, etc., are called shapes. Those of the first mentioned group, which are used principally in steel construction, elevated structures, bridges, etc., are known commercially as structural steel. In addition to the different purposes there exists a fundamental difference between rods and shapes from the rolling standpoint. Aside from the secondary influences the draft with the rectangular cross sections from the first to the last pass, distributes itself by spread uniformly over the whole cross section, which is impossible with shape profiles.

For example, if a channel-shaped cross section 4.724x0.135x0.630-inch were worked backward using uniform draft for flange and web, the deviation from the rectangular cross section, delivered by the blooming and roughing rolls, as shown in Fig. 123, would increase. To obtain uniform draft in all or certain passes, therefore, involves divergence from the rule.

Between the rectangular and the shape profiles lie the round, square and the roughing and elongating passes, with which the draft in every two passes taken together, distributes itself uniformly over all cross-sectional parts. This intermediate type still is consid-

ered as belonging to the regular passes. They also could be termed semiregular passes.

First it is to be determined, that in good pass design the unequal draft is given only in the early passes in which the steel is still hot and plastic. The later passes are designed with equal draft on account of the decreasing plasticity and because with uniform draft distribution the dimensions can be more accurately determined.

How Shaping Is Determined

If the rule of uniform draft is observed at least insofar as the secondary question of spread by the approximate formulas of Geuze or others is concerned, the shaping in rolling can be determined with exactness in advance. This applies for rectangular and shape profiles.

The design of shape passes includes the division of the profile into a number of rectangular cross sections or such which approach them. In Fig. 124 *A*, *B*, *C*, and *D* show such divisions for a rail, angle, channel and tee profile. Smaller intermediate surfaces as the square, *A*, at the point of the angle can be disregarded without introducing a large error. These surfaces are forced by the much larger adjacent parts to the same change of shape. Such places must be kept in mind. If the square, *A*, is considered in the design, then by drawing the center

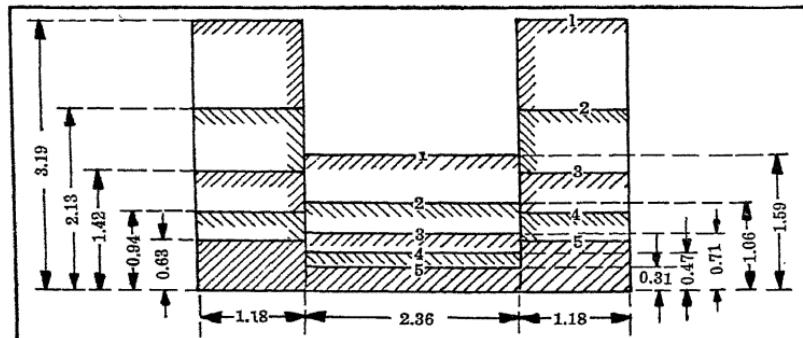


Fig. 123—Diagram Showing Uniform Draft Distribution Over All Cross-Sectional Parts of a Shape

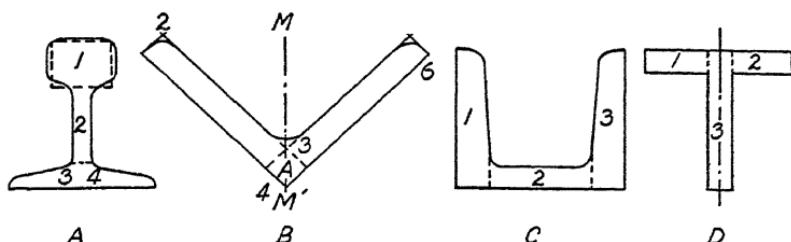


Fig. 124—Division of Shape Profiles into Individual Rectangular Profile Members

line, MM' , the section is divided into trapezoids (1, 2, 3, 4 and 3, 4, 5, 6) instead of rectangles.

To combine the cross-sectional parts, 3 and 4 in Fig. 124 A, or, 1 and 2 in D, would be wrong, for in the horizontal positions of the profile the one part always receives direct draft, while the part lying opposite receives indirect or both kinds of draft. They, therefore, must be dealt with differently.

The procedure with the regular part of the shape pass design, is best made clear by the following section on tees. As with flats, it involves the determination of draft and of the spread and bevels or fillets to avoid fin formation. Only the reductions of the different profile parts must be compared frequently with one another. If they could be brought into accordance with the ideal in each individual pass, or, after several passes, then a good design is possible. Conditions are different with the irregular passes. Here the roll designer has been forced to design by rule of thumb. Missing out in early irregular passes is detrimental because if the first regular pass does not fill, the unfilled cross-sectional parts in the remaining passes receive less draft. If in the intermediate passes the deficiency eventually is evened up, the last will be full and the mistake concealed. Because of the nonfilling in the various passes the stock is subjected to uneven drafts and consequently severe rolling stresses. Tests were made by the author to determine the amount

of the influence of the adjacent parts, or in other words to determine what average length, Lm , a rod assumes whose individual parts receive different drafts. Heyn in a report of the Berlin testing bureau in 1917 called these individual lengths "natural." On making the tests simple shapes were cut into rolls of 13.780-inch diameter, which were divided into ten equal parts as shown in Fig. 125. Of these the first four had the height h , and six of the height $h/2$, then vice versa. Finally, eight had the height h and two the height $h/2$. In the so varied passes at a temperature of about 1000 degrees Cent.

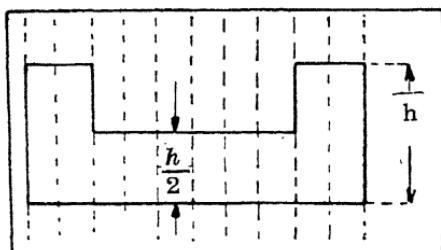


Fig. 125—Layout of an Experimental Section

rectangular rods of a height h and some of a height $0.075h$ were entered. These were the same width as the pass, so that the spread was omitted. Their lengths before and after the pass were measured. The numerous tests resulted in the average lengths of the unequally reduced rods, which approximately were equal to the arithmetical mean of the natural elongation of the individual parts. These had the same cross section before the pass. With the individual tests deviations from 5 to 6 per cent were found. In 23 cases the difference did not exceed 2 per cent.

In answering the question of the average length, that of flow inside the pass also was solved in principle. As the cross section times the length before, equals the cross section times the length after the pass the volumes before and after the rolling must be the same. The

compression of the material, which is free of defects, is small and in most cases cannot be measured. Therefore, $L_1 \times Q_1 = L_2 \times Q_2$. The quantities, L_1 and Q_1 , are known. If $L_2 = L_m$ can be calculated as the arithmetical mean of the natural lengths, Q_2 , the size of the cross section after the pass can be determined similarly if the upper outline of the profile, in the part of the pass which does not fill, is assumed as horizontal.

Mathematically these considerations are expressed as follows: If the spread is omitted due to the small quotients, the increase of the width to the original width of a profile appears possible. The elongation can be expressed by the relation of the height before to the height after the pass. If the natural length is l_2 , the original length of an individual part l_1 , the height before the pass is H , and after the pass h , then $l_2 = l_1(H \div h)$. All individual parts have the same original length equal to the length of the stock L_1 . Consequently, the natural lengths of the individual parts are given by the original heights H_1, H_2, H_3 and the heights after the pass h_1, h_2, h_3 , etc., as $L_1 (H_1 \div h_1), L_1 (H_2 \div h_2), L_1 (H_3 \div h_3)$ etc. The arithmetical mean of these individual lengths is

$$L_m = L_1 \times \frac{\frac{H_1}{h_1} + \frac{H_2}{h_2} + \dots + \frac{H_n}{h_n}}{n}$$

in which n is the number of sections, into which the profile is divided.

Since the volumes before and after the pass are equal, then

$$L_m = L_1 \times \frac{Q_1}{Q_2}$$

Setting these two expressions for L_m equal to one another:

$$L_1 \frac{Q_1}{Q_2} = L_1 \times \frac{\frac{H_1}{h_1} + \frac{H_2}{h_2} + \dots + \frac{H_n}{h_n}}{n}$$

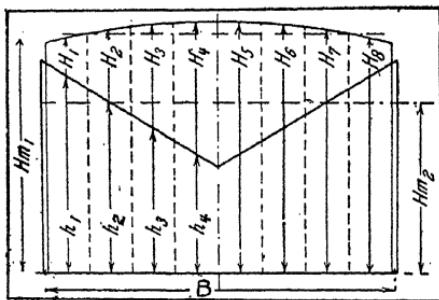


Fig. 126—Arched Outline of an Entered Rod

If the spread is neglected and the profile width denoted by B , the average height before the pass by H_{m_1} , the average height after the pass by H_{m_2} , so that,

$$Q_1 = B \times H_{m_1}$$

$$Q_2 = B \times H_{m_2}$$

therefore,

$$L_1 \frac{BH_{m_1}}{BH_{m_2}} = L_1 \times \frac{\frac{H_1}{h_1} + \frac{H_2}{h_2} + \dots + \frac{H_n}{h_n}}{n}$$

$$H_{m_2} = H_{m_1} \times \frac{n}{\frac{H_1}{h_1} + \frac{H_2}{h_2} + \dots + \frac{H_n}{h_n}}$$

If instead of an arched rod, as in Fig. 126, a square or flat rod of a height H_{m_1} is entered, H_1, H_2, H_3 , etc., are approximately the same height.

If in the foregoing formula in place of H_1, H_2 , etc. to H_n the value, H_{m_1} is substituted this is cancelled from the whole formula. Therefore, where the height of the rod entered is equal to or larger than the height of the profile, the degree of filling approximately must be independent of the thickness of the rod entered. The stock, which in this case stands above the profile, to the greatest part goes into length, not into the cross section. From

the foregoing expression for H_{m_2} , can be determined the height to which a pass of the cross section F is filled if the rod of the width B and the height H_1 passes through. The determination, however, is subject to one assumption:

The upper pass outline must touch the entered rod over the whole width. If for example the latter is lower than the pass, or if the pass is only filled in part as shown in Fig. 127, it would be incorrect to draw into the calculations the heights h_1, h_2 and h_{16}, h_{17} lying in the empty parts of the pass because it is immaterial what height the pass has in places with which this material does not come in contact.

In Fig. 127 the quotients $\frac{h_1}{H}, \frac{h_2}{H}, \frac{h_{16}}{H}$, and $\frac{h_{17}}{H}$ are not to be considered in the calculation. The quotient $\frac{h_3}{H}$

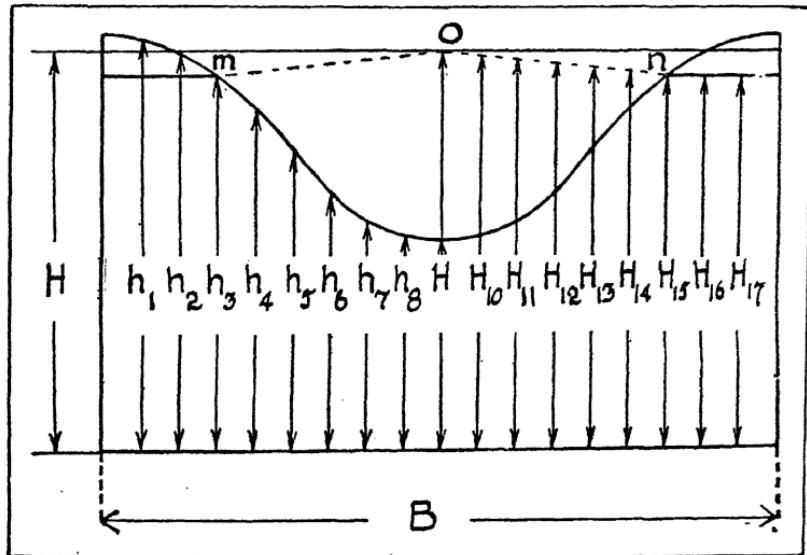


Fig. 127—Outline of an Upper Pass with the Entering Rod Lower Than the Pass

at the place at which the pass just fills, cannot be smaller than 1, because the draft is evidently still equal to zero. At one point it is assumed the quotient resulting from the drawing is smaller than the actual pressure, as is also

the adjacent $\frac{h_4}{H}, \frac{h_5}{H}, \frac{h_6}{H}$, etc. so that with the gradual

transition of the draft equal to zero at the edges up to the maximum draft in the center, a sudden transition can nowhere occur. Therefore, the upper outline of the entering rod must be subjected to a reduction, according to the broken line *mon*. The two legs *mo* and *no* must be straight because the neighboring parts are influenced according to the law of the arithmetical mean.

The reduction, to which the heights of the rod is subjected, is given from the consideration of the procedure in the gripping of the stock by the rolls. As shown in Fig. 118B it occurs first in the center with a cut-in pass and, therefore, at the point of maximum draft, while the parts lying to the right and left at first received no draft. They are pulled along by the center and become lower, until the rolls also grip them when their pressing down effect takes place more rapidly than the pulling down by the forward rushing adjacent parts. At the points *m* and *n* in Fig. 127, where the pass just fills, and in all edge parts lying to the left no rolling down occurs. According to this the reduced rod outline goes

through the points *m*, *o* and *n*. Only the quotient $\frac{H}{h_9}$, in

the middle is to be substituted in the calculation without

a correction. In place of $\frac{H}{h_8}, \frac{H}{h_7}, \frac{H}{h_6}$, in Fig. 127 are

substituted the quotients $\frac{h_8}{H_8}, \frac{h_7}{H_7}, \frac{h_6}{H_6} = \frac{H_{10}}{h_{10}}, \frac{H_{11}}{h_{11}}, \frac{H_{12}}{h_{12}}$.

As with the determination of the height, to which the steel rises in a given pass, the points *m* and *n* are not

known in advance. The calculation only can be made by a cumbersome interpolation. Trial passes were made by the author to create similar conditions and were included in an article in *Stahl und Eisen* in 1909.

Tests Applied to Beam Mill

The first tests conducted on a rod mill were repeated on a beam mill. The investigations determined that the law of the average elongation also held for large roll diameters, and that its transfer from the experimental shape shown in Fig. 125 to larger steel shapes, was permissible. The deviations were small, where the spread was small, but they increased to 5 per cent accompanied by a large spread.

The essential point of the test was, that the rule for the average elongation with the large roll diameters and the pass shapes used in practice, held good. Disregarding the spread, the largest deviations showed up, when the angle of the cutting-in wedge became greater than 90 degrees, but more so, if it became greater than 60 degrees. Indirect, sidewise draft, or cutting if the angle is still more acute, are subject to laws other than the direct draft. Resolving the oblique forces of the wedge-shaped pass into direct drafts and the whole pass surface into individual rectangles, as was done in Fig. 9, consequently is no longer permissible.

The mentioned tests consequently gave, as a secondary result, the evidence that wedge-shaped cutting-in of such passes, often designated as indirect draft, generally can be considered as different direct drafts of the individual cross sectional parts, as long as the angle of the cutting-in wedge does not rise essentially above 90 degrees. In almost all practical cases the mentioned angle remains greater than 60 and 90 degrees.

A pass fills better, the softer the stock. Wrought iron fills better than steel. Hard and cold-rolled metal requires a greater roll pressure notwithstanding the

greater resistance to sidewise movement. Since the latter hinders the sidewise flowing of the material, the average elongation must be greater. That such a coherence exists, can be proven by entering into a pass of about the shape of Fig. 125, a rod which previously has been coated with grease of the highest possible combustion temperature. A roll treated in this way fills better than one ungreased as long as the effect of the greasing exists.

Pressed material fills less than material forged under the hammer. The hammer die recoils immediately after the ensued displacement of material. It releases

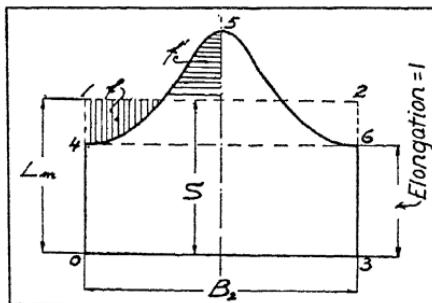


Fig. 128—Elongation Diagram in Which the Spreading Material is Represented by an Elongation $\equiv 1$

the resistance to sidewise movement and the residual stresses, which remain after the ensued displacement, equalize themselves, before the flowing particles of mass come to rest. A sort of afterflow takes place. With pressing the resistance to sidewise movement continues after the displacement of material and hinders the equalization of stress. The pressure of the press remains on the material and makes such an afterflow impossible. The foregoing deviations of the actual filling due to the fluctuations in the roll temperature and the character of the material are of such small importance to the roller, that they can be neglected. They become more important where there is large spread.

In this case, though, it was also possible to bring

about an agreement between the calculations and practice, by entering a value of 1 for the elongation of the spreading material shown in Fig. 128. Its base line is the width of the stock after the pass (B_2). The ordinates

are the relations $\frac{H_1}{h_1}$, $\frac{H_2}{h_2}$, $\frac{H_3}{h_3}$, etc., which to the left of the point m and right of point n , therefore within the spreading material, are to be set equal to 1 ($\frac{H_1}{h_1} = 1$).

The mean elongation L_m then is equal to the arithmetical mean of all the ordinates; or, to determine it from the surface calculation, it is equal to the height, S of the rectangle 0123 , which is equal in area to the diagram surface (surface $f = f'$), or finally equal to the surface 04563 divided by the width B_2 . L_m therefore can be determined rapidly with a planimeter.

Interpolation Is Required

The mathematical determination of how high a pass fills, into which a rod of known cross section is entered, necessitates interpolation and therefore, seldom is used in practice. The problem is simplified if worded as follows: Given a rod or ingot of the cross section Q_1 and a pass of the shape K . Will it fill, underfill or overfill?

In Fig. 129 the assumed pass shape is that bounded by the heavy lines. Does the ingot, $abcd$, fill this pass? The points, to which the steel rises are the highest points of the pass mn inside the ingot cross section. Interpolation, therefore, is unnecessary.

The broken lines, mo and no , are the reduced ingot boundaries. In the case under consideration the pulling in of the material, is placed on the upper side. Assume it is divided between the upper and lower side of the pass, so that, the ingot sticks out on both sides of the pass an amount $am \div 2$ and $bn \div 2$ respectively. The result is the same as a consideration of the ordinates so formed.

The spread is neglected; the ingot width, B_2 , will be put in as the pass width. One ordinate is placed in the center of the pass; it is the height of the smaller inner rectangle. The width of all rectangles is taken as b , the next rectangle must be a distance, b , from the center one; contrary the two outer ones are a distance $b \div 2$ from

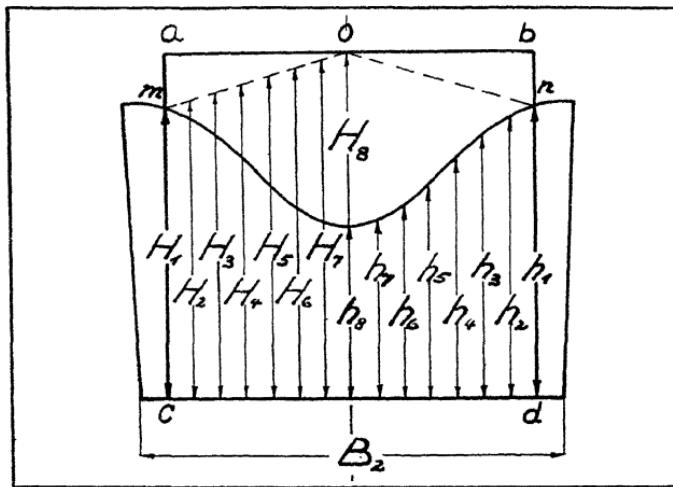


Fig. 129—An Assumed Pass Shape, the Broken Line Representing the Reduced Ingot Boundary

the edge. The error is insignificant if the distance between the ordinates is small.

With symmetrical profiles the middle ordinate only occurs once, while those to the side occur twice in equal size, therefore, only one-half of the pass need be drawn. Under the supposition, that the pass actually fills, according to the previous section, the average length of the ingot L_m is determined from the 15 rectangles of Fig. 129 as follows:

$$L_1 \times \frac{2\frac{H_1}{h_1} + 2\frac{H_2}{h_2}}{15} + \frac{2\frac{H_7}{h_7} + 2\frac{H_8}{h_8}}{15}$$

From this we get $L_1 = 1$ and setting $Q = \text{width} \times \text{height}$, from the equation $L_1 \times Q_1 = L_2 \times Q_2$, that is, from the constant volumes: $1 \times B \times H_b = L_m \times B \times H_m$ and from this the average height, which the ingot shows after rolling, that is, if it were to fill the pass, as $H_m = H_b \div L_m$ with L_m the average elongation, then according to the foregoing

$$2 \frac{H_1}{h_1} + 2 \frac{H_2}{h_2} + \dots + 2 \frac{H_s}{h_s} + \frac{H_n}{h_n}$$

\dots n

H_b is the height before the pass or the height of the ingot. The average height of the pass is found as the arithmetical mean of the 15 individual heights of the pass. In Fig. 129 it is:

$$h_n = \frac{h_s + 2h_7 + 2h_6 + \dots + 2h_1}{15}$$

To answer the question as to the filling of the pass now necessitates setting H_m and h_m opposite one another. If $h_m > H_m$, the pass underfills. If $h_m < H_m$, the pass overfills, and results in fins. If the two are about equal, the chosen pass shape will be filled by the ingot.

Investigating irregular pass designs mathematically by the method instituted by the author will be as useful to the experienced, as to the novice in roll design.

The graphical determination of L_m can be substituted for the mathematical. For this purpose the elongation diagram which previously was used in the design

of elongating passes, is drawn with 1, $\frac{H_1}{h_1}$, $\frac{H_2}{h_2}$, \dots , $\frac{H_s}{h_s}$

etc. as in Fig. 128 and with the width equal to the pass width as in Fig. 129. If the area found with the planimeter is divided by B_2 , the value of L_m is obtained. A simple procedure to find the average height is to open a compass to the size of the first ordinate, set it at the beginning of the second and open it to include the second. The sum of two ordinates thus is obtained. This is continued

Table IX
Table for the Design of a 1.969" x 1.969" x .276" Tee

PASS NO.	HEAD RIGHT				HEAD LEFT				FILLET RADIUS					
	d	d	Q	Q	d	d	Q	Q	d	d	Q	Q	d	d
VI	0.994	0.276	0.276	0.274	—	0.994	0.276	0.276	0.274	—	1.713	0.306	0.345	0.472
V	0.974	0.345	0.374	0.317	1.15	0.974	0.325	0.325	0.317	1.15	1.850	0.276	0.276	0.510
IV	0.906	0.325	0.358	1.13	1.102	0.325	0.325	0.325	0.358	1.13	1.811	0.384	0.417	0.606
III	1.043	0.394**	0.411	1.15	1.043	0.413	0.452	0.411	1.15	2.028	0.335	0.335	0.679	1.12
II	1.122	0.394*	0.512	0.508	1.24	1.181	0.374**	0.413**	0.465	1.13	1.949	0.433	0.433	0.844
I	1.428	0.394	0.571	0.693	1.36	1.428	0.394	0.571	0.693	1.49	1.161	0.669	1.575	1.304

* The thickness, d , is not determined from the pass, because it does not fill in width, but from the previous pass.

** d should be made 0.010" narrower in the design because of the side spring.

until the compass cannot be opened any further; the size of the opening and the number of measured ordinates are recorded. This procedure is repeated until all ordinates have been taken up by the compass.

Average Height Is Determined

The sum of the compass openings divided by the number of ordinates is the desired average height. The two-lined curved surfaces 2, 3, 10 and 1, 2, 8 therefore must be equal. They form a measure of the material flowing off inside the pass plane from the more centrally pressed cross-sectional part into the less-pressed edge parts and therewith a measure of the retained residual stresses in the profile after the accomplished flowing process. The elongation diagram thus forms a further means to the roll designer to judge the flow procedures in rolling uniformly-pressed cross-sectional parts.

So far only rectangular starting profiles with the same height over the whole cross section have been considered. If the starting profiles are of different heights, as for example a billet entered diagonally in the bell pass of a T-design or in a first beam pass, which is entered into the second pass, the foregoing conditions only change in so far as instead of dividing the pass to be investigated in rectangles of equal width, they are made of equal surface. From their average heights

$$L_m = \frac{\frac{H_1}{h_1} + \frac{H_2}{h_2} + \dots + \frac{H_n}{h_n}}{n}$$

For the calculation of the average pass height, equally spaced ordinates again must be used.

The tee shows clearly the division of the whole profile into single rectangles and the calculation, according to the reduction relation. As an example a tee 1.969x1.969x0.276 inches is chosen. Its hot profile is 1.988x1.988x0.276 inches. The designs are made from the last or hot profile backward to the first pass. In Table IX

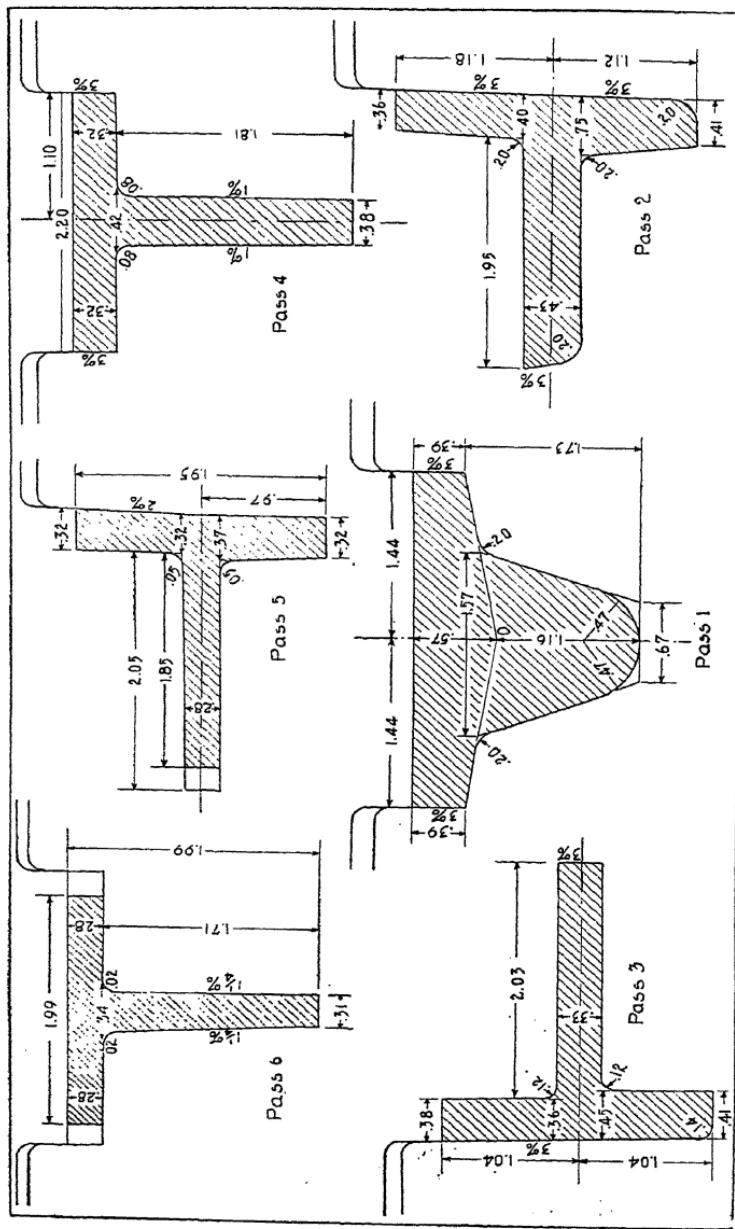


Fig. 130—Pass Layout of a Tee Using the Various Dimensions Tabulated in Table IX

are determined the chosen thicknesses d , and heights, h , that is, the web and the right and left halves of the head. These then are transposed to the pass drawing, shown in Fig. 130.

From h and d the cross section is calculated. If the surface of a part of the pass so determined is divided into that of the previous pass, the natural elongation, n is obtained. Sizes h and d are found as follows: First, the draft and thickness in the lowest horizontal profile part are decided. In pass 6 the head is horizontal. A draft of 0.049-inch is chosen for pass No. 5 from a reduction stepping for flats or hoop iron. A thickness of 0.325-inch in this pass, therefore, is obtained.

Conditions Affect the Spread

Where the elongation is the same in all parts of the profile, the spread in each as with flats is 0.25 to 0.35 times the draft, according to Geuze. If the elongation is retarded in some parts, the spread will be larger in the adjacent parts as was previously shown. The spread is taken from experience as 0.039-inch in the head and the height of the head in pass 5, as 1.949 inches. Unfortunately the increase of the spread cannot be calculated due to the influence of the less elongated adjacent parts. The material held back flows partly into the more strongly pressed neighboring section and partly into the width. The flow to each side is unknown. The more steel that goes into the width, the harder it is for the material to give way into the neighboring part, particularly if the latter only borders on one side instead of on two and if the angle of the direction of flow is steep. Both conditions apply in the case with tees.

Only indirect draft can be exerted on the thickness of the vertical parts. Where the vertical part lies above, up to 40 per cent of the indirect draft, according to the temperature, can be used at the point where the pass parting lies. The draft determines the thickness since $d \times h = Q$ and also the height h , as soon as the value for

Q is known. In pass No. 5 indirect draft is avoided.

If the draft and the spread are determined as mentioned the cross section and the natural elongation are available. If the latter is to be the same size for another profile portion, this cross section Q_2 also is given. Therefore, it is only necessary to multiply that of the previous pass, Q_1 , by this elongation, or, 0.472-inch \times 1.15 inches. The former value is the web section after pass No. 6 as shown in Table IX; the latter value was calculated from the draft and spread of the right and left halves of the head. This would give a web section in pass No. 5 of 0.546-square inch. Since the web thickness in pass No. 6 is 0.276-inch and since the slight upsetting in the finishing pass as with flats is neglected, the height of the web would be $0.546 \div 0.276$ or 1.969 inches.

In the table an elongation of 1.08 is given instead of 1.15, which corresponds to a web height of 1.850 inches instead of 1.969 inches. The vertical part is permitted to remain 7 per cent behind the horizontal. The purpose for this is to keep the spread of the web low and to work in opposition to it by shrinkage, which is the case with unequal elongation. If this practice is not followed there is the danger that the web is upset and wedged in. With such deeply cut-in pass parts the stock frequently wraps around the rolls, filling the pass and often wedging itself tightly.

Stock Subject To Strains

Holding back the stock too little, increases the dangers just described, while too much results in strains in the stock, which when the rolling is executed too long, causes tearing-in. This results in bad ends, and, greater roll wear and use of power. Roughly, the 5 to 15 per cent difference in the elongation can be designated as permissible, 5 per cent in the latter and 10 to 25 per cent in the first regular passes. Or, if the web were given no draft and, therefore, an elongation of 1, the average elongation of the entire tee would be $(1+1.15) \div 2$ or 1.075 because the web retards the approximately equal

sized head the same amount as the head pulls along the web. If the shrinkage, due to being pulled along, proceeds at the expense of the height, an allowance of $1.713 \times 1.075 = 1.841$ inches must be made so that the shrinkage is accompanied by the rolling draft. In Table IX a height of 1.850 inches was chosen. Moreover the whole shrinkage does not take place at the expense of the height, but partly at the expense of the thickness of the web. While a slight upsetting of the web thickness occurs this does not occasion any exceptional spread, nor does it cause wedging-in, but irons out a part of the resulting rolling stresses. This calculation only is approximately correct. Actually the flowing from the web toward the more strongly elongated head does not occur uniformly over the whole cross section. The more the flowing the nearer the particular part of the web is from the head and vice versa. Near the head often is found a shrinkage of the web thickness or at the opposite end a spreading or upsetting. The calculation gives average values only. The design, however, is more accurate if the values are considered.

Free Spread Is Permitted

The last and next to last passes are permitted to spread freely to prevent the formation of a fin standing perpendicular to the web or the head. Therefore, open passes are used for the web. In pass No. 5 such a fin would increase the wedging-in danger in the following pass. Beginning in pass No. 4 the horizontal part is permitted to run against the side in order to receive sharp corners. Here the pass is closed.

Indirect draft from pass No. 4 into pass No. 5 is not given. It could be used above but not below. If it was on one side, an unsymmetrical fourth pass would result. This is not impossible to do, but undesirable. It complicates the entrance guides and the exit guards and influences the stock to leave the rolls crooked. Avoidance of a side draft is preferable because under this condition a head thickness of 0.325-inch is obtained in pass No. 4.

The spread of the web is taken as 0.039-inch and its height as 1.811 inches. The web thickness, which is 0.335-inch, is not determined in the edging pass, but in the previous third pass. The edging pass must be wider considering the danger of wedging in. Widths of 0.384-inch are chosen for below and 0.417-inch for above equal to a taper of 1 per cent. According to the foregoing an elongation of the web equal to 1.19 results from the fourth into the fifth pass; in the head it is chosen as 1.13. A cross section, therefore, is received of each side of the head of 0.317×1.13 or 0.358-square inch and a height of $0.358 \div 0.325$ or 1.102 inches. In the same manner the dimensions of passes Nos. 3, 2 and 1, respectively, are determined.

Arrangement Affords Deep Passes

In passes Nos. 2 and 3, which differ from No. 5, indirect draft is used on the part of the head lying in the upper roll. By this arrangement smaller direct draft can be chosen and less deeply cut-in passes received.

As the stock is turned 180 degrees from the second into the third pass, indirect draft is received on the left side, and in the next pass on the right side of the head; the unevenness, therefore, is evened up. Heavy one-sided indirect draft causes a sidewise spring of the rolls. If for example at the point in the upper part of pass No. 2 a thickness of the head of 0.374-inch and at the base 0.413-inch exists, which is shown in Table IX, the pass must be made lighter, in order to counteract in advance the unavoidable sideward giving-way of the rolls.

The size depends on the one-sided indirect draft and the roll diameter. With double sides, as with beams and channels, this springing does not occur, because the side drafts counteract each other. With side drafts less than 0.039-inch the sideward spring is so small, that it may be disregarded. Small rolls give way more than large units on account of the small bearing surfaces. Ordinarily 0.10 to 0.20-inch is provided for the sideward

spring. In the second and third passes 0.010-inch is taken.

In the head of pass No. 3 a fillet of 0.138-inch radius is used. It is chosen large because the entered stock is 0.039-inch narrower than the pass and, therefore, the fillet can give way this amount. Moreover, part of the fillet is rolled out in the fourth pass. It is made 0.059-inch in the fifth pass which suffices to prevent the formation of fins. In the web, no fillet is necessary in pass No. 3, because it is permitted to run free in pass No. 5. The head in the second pass and the web is given large fillets of 0.197-inch radius because they should preserve

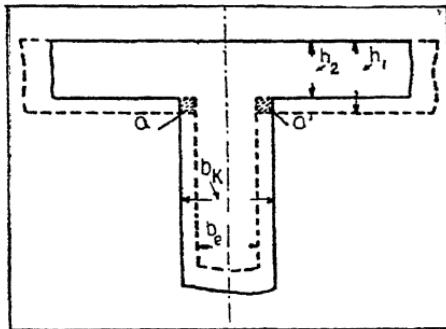


Fig. 131—Onset at the Transition of Web and Head

themselves through two passes; both do not work out fully in so far as the pass does not entirely fill in width. Fillets, which are too large, can be corrected easily but those too small are difficult to change.

The narrower the edging passes are made, the greater the danger of wedging-in. If to prevent this it is made wide, offsets are formed in the corners in the change from the web to the head $\alpha\alpha'$ as shown in Fig. 131. The reason for the offsets is that a pass made too wide does not reach into the angles of the profile with its corners and, therefore, cannot squeeze away material from the head at the desired points. This moreover retains over the width b_k the original thickness h_1 , while to

both sides it is pressed down to h_2 . These offsets, which are difficult to prevent with a sharp cornered tee, represent a defective appearance in the finishing pass; with roughing passes, as with pass No. 4, they later can be squeezed away, the corresponding places on the roll being stressed considerably and easily spall off. An intermediate value for the width, therefore, is chosen for which the design under consideration may offer a starting point.

An efficient arrangement of finishing and roughing passes is to put the roughing passes on a 3-high or a double 2-high mill and the finishing passes on a 2-high mill. To prevent roll impact it is advisable to permit the upper finishing roll to run by friction. Its diameter can be made 1.969 to 3.937 inches smaller than the remaining rolls to afford efficient operation.

To minimize the number of passes on the 3-high and to be able to roll fast, the second last pass also may be put on a 2-high mill. The arrangement in this case is about as follows:

Pass No. 1 on the 3-high below
Pass No. 2 on the 3-high above
Pass No. 3 on the 3-high below
Pass No. 4 on the 3-high above
Pass No. 5 on the 2-high below
Pass No. 6 on the 2-high above

Fillets are provided at the points in the following pass when the groove is open; they are purposely chosen larger for open and smaller for closed passes. The position and size, therefore, depend on the type of this opening. The opening is denoted in the pass drawing, as shown in Fig. 130. If this were not done and the roll drawing was finished by another, the fillets of the one and the openings of the following pass might not correspond.

The amount of spring in the design at the parting also can be entered. This was not done in Fig. 130 because it is dependent on the size of the roll diameter and on the layout of the passes on the rolls. If, for ex-

ample, all the passes are placed on alloy rolls and a spring of 0.079-inch is provided in the finishing pass, 0.157-inch in the first and second passes on account of the large draft, and, 0.118-inch in the other passes then these values are entered between the parallels which denote the parting lines of the rolls at the pass openings. The roll drawing is finished accordingly and the rolls turned. In the roll stands the latter are pressed against one another by the spindles. If on entering the stock they actually spring the amount previously mentioned, the profiles have the desired heights during the pass. If they spring less, the upper roll is raised somewhat before the pass. If they spring more, the pass becomes too thick in the parts of the profile having direct draft. The web of pass No. 3, therefore, would no longer enter the edging pass No. 4 or would wedge itself in and thus endanger the rolling. It must be obvious that the spring design always should be made larger but never smaller than the actual spring.

Spring Causes Variations

Conditions are different if passes Nos. 1, 3 and 5 are placed on one roll, and passes Nos. 2, 4 and 6 on the second set of a double 2-high or a 3-high stand. If pass No. 2 were given a spring of 0.157-inch, pass No. 4 a spring of 0.118-inch and pass No. 6 a spring of 0.097-inch, the rolls could only be pressed together 0.079-inch because of pass No. 6; and passes Nos. 2 and 4 become too heavy. If, however, a spring of 0.157-inch is provided in all passes, the finishing will be 0.079-inch too low. To pull up the rolls each time between the second and third and the third and fourth passes would not be feasible. In such a case nothing remains but to give all passes the same spring, as in the example 0.079-inch, and for the rest to gain 0.039-inch and 0.078-inch by holding the particular pass lower. All heights then would have to be reduced such as 0.079-inch for pass No. 2 and 0.039-inch for pass No. 4. The amount of spring, therefore, can only be set, if the roll diameter and the manner of distribut-

ing the passes are known. This, as a rule, is given first in the roll drawing. The roll turner uses the templates finished according to the pass design and arrives at the reduction of the heights of passes Nos. 2 and 4, which are entered on the roll drawing. In holding the templates, which are too high, the rolls are pulled apart 0.118-inch with pass No. 2 and 0.157-inch with pass No. 3, while the distance between them, in the case of template 6 as in the setting into the stands, amounts to 0.079-inch. It is better though, to keep this reduction in mind when designing the passes, so that the roll turner has nothing to do with this. For the remaining passes the unequaled spring is important only where the profile is turned 90 degrees; it is insignificant where the profile lies flat, as with channels or H-beams.

Regular Passes Are Unknown

An absolute regular pass design never is encountered because the elongation, at least in the final passes, must be equal for all parts of the profile. That part always in the next pass experiences a greater elongation, which remained behind in the previous pass. As previously mentioned such pass designs are known as regular or semiregular. From the second to the sixth pass the total elongation in the right side of the head is $0.508 \div 0.274$ or 1.85 and in the left side of the head 1.7 or an average therefore of about 1.78. In the web it is 1.79 or approximately equal.

The elongations from pass No. 1 into pass No. 2 shown in Table IX refer to the ideal halves of the head prolonged up to the section with the axis which is designated o in pass No. 1 of Fig. 130. If only the horn-shaped free surfaces of the head considered in pass No. 1 were taken as a basis for calculation, the disproportion of the elongation between the head and web from the first into the second pass, would become considerably larger. The first pass already lies in the zone of irregular pass design and with this, in most cases, the exact and definite division of the individual parts of the profile cease. Either

a greater or lesser number of hypothetical assumptions must be made or the determination of the elongation omitted and the filling judged according to the method outlined in the discussion of fillets.

The first pass often is called the bell pass. The stock entered in this pass is a blunt cornered square or gothic turned upon one corner, having a length of side of about 2.047 inches or a diagonal length of about 2.864 inches. The custom is to start with a square equal to the width of the head of the tee, or 1.181x1.181-inch for a 1.181-inch tee, 3.150x3.150-inch for a 3.150-inch tee, etc. The blunt corners provide the spread and the relative draft, which with sharp corners is about 40 per cent, still is reduced slightly.

The spread of the bell pass is assumed as 0.787-inch which is somewhat larger than three times the normal spread or 0.3×0.630 equals or approaches 0.189-inch. Precaution is necessary the same as with fillets. Pass No. 2 does not fill in the width, with the result that pass No. 1 is turned somewhat deeper. If on the contrary it had been chosen too deep, all the rolls would have had to be turned down completely, to receive a shallower pass.

Certain Passes Are Narrower

Edging and lateral springing passes such as pass No. 2 in Fig. 130 are narrower than the profile leaving the roll. In the same way passes Nos. 5 and 6 are broader than the stock after the pass. It should be remembered that the stock does not always conform to the shape of the pass. In new pass designs where the differences are considerable, the outline of the stock after the pass also should be incorporated in the layout as was done in Fig. 130, passes Nos. 5 and 6.

Pulling along has not been considered in the present pass design. The roll diameters are assumed to be from eight to ten times the height of the profile, which equals or approaches 19.685 inches, in order to be able to neglect the pulling effect. If the diameters were

smaller, the corners of the web, due to the pulling along, would shrink and, therefore, would not fill completely. A larger indirect draft or smaller fillets, therefore, must be provided at those places. The fillets are only definitely determined after the first setup of the rolls, so that the consideration of the pulling along can be combined with this correction. With especially small diameters the fillets might no longer be sufficient for adjustment, so that compensation for the pulling along should be made at the beginning by increased indirect draft.

Draft Assures Gripping

Gripping of the rolls, in the bell pass is assured because of the 40 per cent draft. The draft from the first into the second pass is $(0.709 \div 1.142) \times 100$ equals about 60 per cent. This is about 10 per cent too much. In order to have better gripping either the web is made conical, about 0.433-inch on the left, 0.669-inch on the right equivalent to about a 50 per cent draft; or, indentations are provided on the rolls in the train.

The essential point of the pass design under consideration is, that the parts of the profile subjected to the wedging-in are held back 5 to 10 per cent in elongation, but that up to pass No. 2 the total elongation in all parts of the cross sections is the same. This latter compensation and the one from pass to pass may be obtained by making a greater use of the retardation. In fact that often is done in practice.

Even if the strains in the whole process can be equalized, they are large in the individual passes. Crop ends, increase because the stock becomes defective at the ends for a greater length and secondly, because with such pass designs the lengths, which can be rolled, are shorter. Strains with cross sections subjected to unequalled draft increase from foot to foot, and therefore under certain conditions may be safe at 49.213 feet. With 82.021 feet however, tearing or a sudden slip in the rolls may cause a defective place in the stock. This explains why improperly designed passes will work without difficulty, if

the lengths of the stock are chosen small enough. In perfect pass designs the length of the stock can only exert an influence, in as far as the rolling temperature is dependent on it. Another important point is, that shaping is accomplished principally in pass No. 2.

An angle consists of two rectangular cross-sectional parts perpendicular to one another; one part always gives the other stiffness against lateral bending. A round-cornered angle is shown in Fig. 132A, and an unequal-legged, sharp-cornered angle in Fig. 132B. Other types

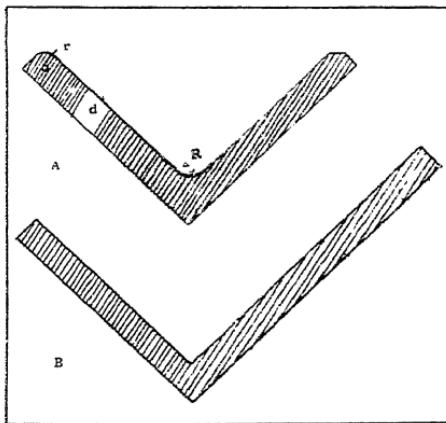


Fig. 132—Types of Round and Sharp Cornered Angles. $r = (D \div 2)$, $R = D$

include sharp-cornered, equal-legged and unequal-legged angles.

As previously shown the tee is entered in the first pass with a square or approximately square cross section, in which one diagonal is placed vertical and the other parallel to the roll axes. The largest draft is in the center. The square profile fitted itself to some extent into the bell pass, which also had its largest height in the center and its smallest heights in the perpendicular ends to the right and left. Different conditions maintain with the angle iron. If a square were to be entered in the

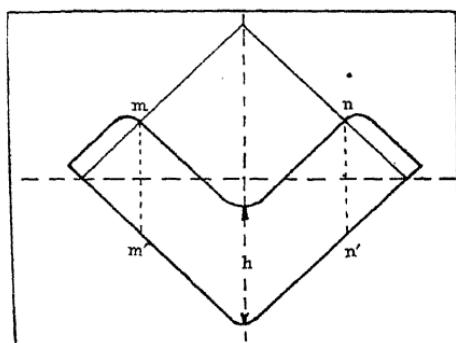


Fig. 133—Diagram of a Square Entered Diagonally into an Angle Pass

first pass as shown in Fig. 133 the relation of the draft in the center to that at the ends would be more unfavorable than in the bell pass. According to the figure the pass would be so large, that the square billet probably would no longer be gripped by the rolls. On the other hand there would be no draft to the left of mm' nor to the right of nn' and the legs would be empty. The underfilling probably would extend beyond these lines toward the center, because the outer cross-sectional parts are

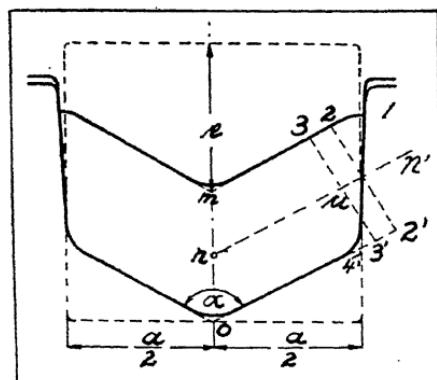


Fig. 134—Diagram of a Square Billet Entered Flat into the First Angle Pass

pulled along by the heavier draft in the center. At any rate a crippled section in place of a full first pass will leave the rolls. According to the theoretical investigations on the filling of a pass, nothing is to be gained by raising the roughing roll to give more iron; nor would the addition of one or two roughing passes help. In fact, the draft in the center would be reduced. While the rolls would grip better the ends of the legs would receive still less draft because their height increases the same amount as the center, and therefore the legs would underfill over a still larger area. Such a method of entering therefore is not advisable. The billet from the roughing rolls should be entered flat into the first angle pass according to Fig. 134.

In the center of the angle, as shown in Fig. 134,

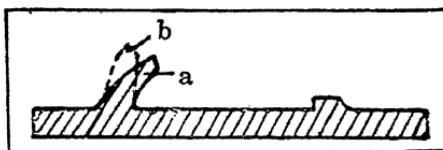


Fig. 135—Diagram of a Hook-Plate Profile

a thickness of material, e , must be displaced. A kind of bending of the square to an angle occurs. A bending or folding-up of a profile often is a necessity or an aid in roll pass design. It is indispensable with the so-called backed off, that is, profiles in which one cannot get into with the roll, as for example the hook-plate profile shown in Fig. 135. The horn, b , first is formed straight as indicated by the dotted line and the last pass is used to bend the horn into the position a . The draftless bending or folding avoids the danger of tearing especially if the stock is already cold. Where the folding cannot be eliminated it is advisable to allow more iron in the shaping pass at the particular place, similar to the blacksmith who upsets a bar he wants to bend. The same purpose can be accomplished, if while bending, the whole leg can be given draft, as is possible with the angle pass.

Two disadvantages remain, however, even though the danger of tearing open is avoided.

1. The place, where the material bends upward is not exactly fixed. In Fig. 135 for instance, as the square is narrower than the angle pass, there is no assurance that it will bend up exactly in the middle. Therefore, such profiles have a tendency to go through the pass one-sided, that is, the one leg easily becomes somewhat longer than the other.

2. By the bending upward, the outer fibers of the leg are in tension and the inner in compression. This makes the spread of the leg difficult to judge, and causes the angles, which the side edges of the legs make with the leg axis, to change as the result of the bending up. If they were perpendicular before, they will not be afterwards.

The tendency of an angle to go through the pass one-sided may be reduced by eliminating spread (measured horizontally) and giving about 10 per cent more taper. In this way the stock is centered at the instant of entering the pass, that is, forced to stay exactly in the center of the pass. This object cannot be accomplished by closely set guides because a certain space always intervenes between the guides and the rolls. The space is sufficient for the stock, which, as was previously mentioned, is also always subjected to certain sideward forces acting in the roll plane. The stock, therefore, gives away against one side of the pass. This condition, as will be understood readily, leads to unequal filling.

Another method for centering is the so-called butterfly method. The bending up is transferred from the point of the angle to be folded toward the center of the leg as shown in Fig. 136, or is distributed over the whole length of the legs as shown in Fig. 136. In both cases the angle α at the vertex is 90 degrees before folding up; it takes no part in the bending up but helps to hold the bar in the pass. The advantage of the first method is the slight influence on the angle β at the corners as shown in Fig. 136.

Disadvantages of these pass designs are that they tend to break at the bent portion, or to draw or leave linear marks if the breaking effect is counteracted, by giving draft. Moreover, such profiles, usually are broader before bending up than before the following pass and,

therefore, are inconvenient to enter into the gap of the rolls. They must be guided into the pass at an angle and since this position is difficult to judge exactly, the advantage of centering again is endangered. For these reasons the bending-up design seldom is used in pass layouts although recently it has become popular again.

The bending up action with the flat entering of the square cross section coming from the roughing rolls, is

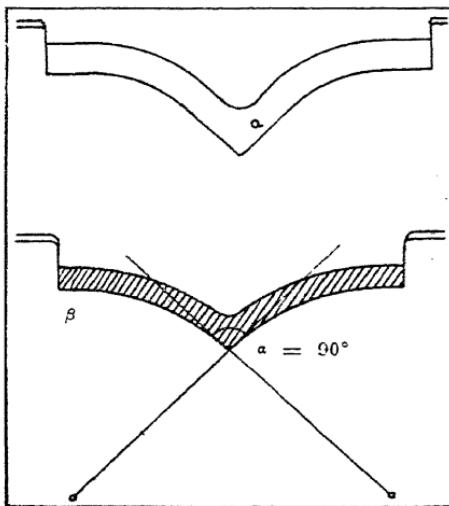


Fig. 136—Design for Bending Up Angle Legs

unavoidable at any plane of the angle pass design and can be reduced since it is done in several steps, progressing from pass to pass. The apex angle, α in Fig. 134, is made larger than 90 degrees in the first pass and is reduced from pass to pass so that it becomes a right angle in the last or better in the next to the last pass. To avoid any pulling or influencing of the edge of the legs or a tendency to tearing, and to obtain an exact dimensioned product no bending should be done in the final pass.

Kirchberg suggests, in designing backward from the finishing profile, to increase the apex angle 5 degrees in

each pass. Geuze advises, to choose from 142 to 145 degrees for the first pass and to divide the remaining 52 to 55 degrees among the different passes proportional to the drafts. For the four last shaping passes the drafts, which are the differences in the leg thicknesses, are chosen 0.098, 0.315 and 0.728-inch while the draft from the square to the first pass amounts to 1.457 inches. This gives a total of 2.598 inches. Accordingly, the angle, α , in the fourth pass equals $90 + 55(0.098 \div 2.598)$ which equals or approaches 92 degrees. As previously mentioned it is advisable to make it 90 degrees. The angle in the third pass equals $92 + 55(0.315 \div 2.598)$ or 99 degrees; in the second pass it equals $99 + 55(0.728 \div 2.598)$ or 114 degrees; and, in the first pass $114 + 55(1.457 \div 2.598)$ or 144 degrees. This method has advantages because the bending-up can be accomplished without danger, the more draft that is given. Moreover, the 55 degrees is more equally distributed over the different passes.

How Centering Is Achieved

As previously mentioned the centering can be achieved by making the previous pass, measured horizontally, as broad as the one to be entered. Actual spread may be given because the width in question is that of the whole pass measured at the rolling line. On the contrary the spread refers to the single legs; it is the difference of their lengths and is measured in the direction of the leg. It may be different for the top and bottom of the leg. A series of movements such as the bending up and the pulling along to which material is subjected when leaving the rolls on its top and bottom side, tend to keep the spread of the angle legs low. For an angle 90 degrees it can be set at about 20 per cent of the normal spread of a simple rectangular cross section and 50 per cent for an angle 145 degrees.

Some roll designers refer the spread to the neutral axis of the legs, nn' in Fig. 134. They make the length

of the leg, nu , equal to half the side of the square, draw the outlines of the legs, 3—3', perpendicular to this and consider the spread by a corresponding parallel displacement of this line to the right. (Ends of the legs 2—2') Due to the oblique pass outline the piece 2'—4' must be taken from outside part of the leg and put at the equally large inside piece 1—2. (See Fig. 134.)

Range of Spread To Be Given

It would be more exact to assume for the pivot of the bottom fibers the point o and to give it, according to the steepness of the angle, a spread ranging from 0.2 to 0.5 of the normal or from 0.07 to 0.175 of the draft. For the inside leg length the point m is taken as the pivot. On account of the taper of the pass it usually will be too long, so that in turning the section 180 degrees (Fig. 138) no spread will occur, but rather an upsetting results. This is immaterial if the pass is closed at that point and if the total width measured horizontally is less than the previous pass.

Draft and fillets for the legs can be taken from Table II for flats. R (Fig. 132A) therewith must increase gradually, r decrease, with increasing leg thickness, so that the draft in the fillets is proportionally equal to that of the legs.

If the pulling along, due to the unequal working diameters, is to be considered, more stock must be added at the ends of the legs and in the center of the pass as is the case at the right side of Fig. 137. This often was done at the ends but it is preferable to make the outline straight, as shown at the left of Fig. 137. The correction would be small, as shown in the previous calculation and, as shown in Fig. 134, the inner leg generally becomes longer in the next inverted pass (Fig. 138) on account of the taper, so that it experiences an additional upsetting in the following pass.

The opening in the first pass generally is taken as in Fig. 137. The second pass purposely is turned to en-

able the corners at *a* to be pressed as shown in Fig. 138. These preserve themselves in the remaining shaping passes, so that the opening always can be put in the same place or, according to Fig. 139, on the outer side of the angle. The opening, according to Fig. 137, no longer is permissible, because it prevents square edges.

The slight spread in the last passes may be neglected; the finishing passes for the heavier angles can be used as the shaping passes for the lighter angles. Three finishing passes 0.197-inch, 0.236-inch and 0.315-inch thick are provided, all with the same length of legs, and the final rolling is done either in the 0.315-inch pass or the section leaving this pass is entered in passes Nos. 5

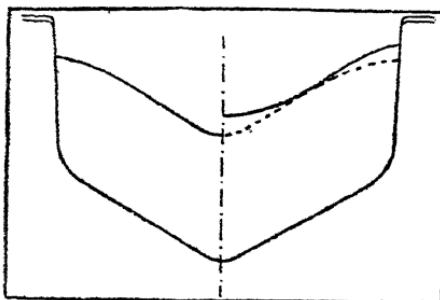


Fig. 137—Scheme for Adding More Stock to an Angle Profile

and 6 where these thicknesses are required. This is preferable to raising the rolls because in the latter method with the increase in leg thicknesses, the length of the leg also increases. Rolling angles of different thicknesses in the same finishing pass gives inexact leg lengths as a result.

To hold the legs closely to dimensions and to prevent underfilled edges, the passes should permit the formation of overfills, which then can be cut off after cooling of the stock by a machine for removing fins. The removal of fins also can be combined with the cold straightening, which is unavoidable because of the crooking of the angles on the hot bed.

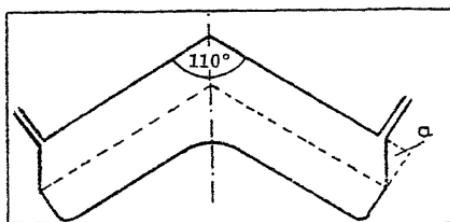


Fig. 138—Shape of an Angle After the Second Pass

Conditions applying to unequal-legged angles are exactly the same as with equal-legged angles, with one exception. With the latter type the lateral forces neutralize each other while with unequal-legged angles the larger leg offers greater resistance to the material displacement than the shorter. This condition influences the rolls to give sidewise in such a way that the long leg becomes thicker. To compensate for the influence on the thicknesses, a heavier draft must be given in the shorter leg than in the longer, according to the size and the thickness of the profile.

Procedure for Angles Is Complicated

It must be obvious that angles offer serious difficulties. The flow procedures in these profiles, which are simultaneously influenced by the draft; the pulling along and upsetting due to the bending up; and, the difference of the working diameters in the bottom as at the ends, are extraordinarily complicated. It, therefore, is not admissible to design angles as flats in tables. Regular pass

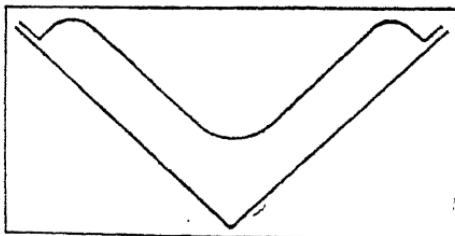


Fig. 139—Shape of an Angle After the Last Pass

drawings must be made. Each pass should be traced and laid on the previous and following passes, as was shown, assuming the pivot for the bending up of the legs above and those below and remembering that the upper fibers are upset with this method. By this arrangement sharp ends perpendicular to the legs, exact dimensions, and, filled leg ends without fins are possible.

How Channel Passes Are Designed

Channels are distinguished by open and straight pass designs. With the former the flanges in the shaping pass are bent slightly similar to the bending up of angles. To hold a right angle between the flanges and the web necessitates arching the web in a bow shape as shown in Fig. 140. The object of the bending up is to permit roundings off at α and to prevent fin formation in event the opening of several passes following in rotation is put at the same place. The larger the angle, α , that is, the inclination of the flange to the horizontals, becomes the greater the amount of folding that can be obtained. That is the reason channel passes can be designed by this method without turning. This is desirable because the turned-up channel pass will wedge in much easier in the cut-in sections that are worked by direct draft than the tee. To avoid this, as with the tees, small draft must be used in the final passes. This increases the strain between the heavier stressed web and the flanges, for which there is no compensation with the flat-lying channel pass as compared with the tee turned 90 degrees from time to time. The advantage of the open pass design, therefore, is that it requires less passes, because indirect draft is used in each pass, and consequently, promotes a better development of the flanges. Therefore, wedging-in and collaring will not be encountered. The disadvantage is, that as the flanges always are open at the same place, it is difficult to develop their heights equally and their ends sharp and clean. This latter disadvantage is avoided by the straight pass design, which in the turned passes, always upsets the

flanges to the exact size and, facilitates smooth under-filled or overfilled corners. In addition less space is required on the rolls.

A method sometimes used with profiles having a flange on one side is the so-called counterflanges in the shaping passes. A part of the flange is placed on the other side of the pass as shown in Fig. 141 so that the grooves in the rolls on the actual flange side are not so deep. Experience shows that in pressing away the lumps thus made in the last or next to the last pass the material goes into the flanges easily.

In Table X are various dimensions for and in Fig.

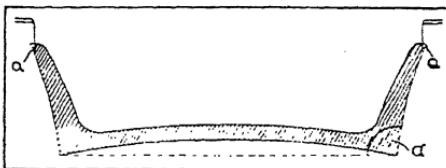


Fig. 140—Design of an Open-Channel Pass

141 details of the pass design for a 4.724-inch channel. The procedure, from which it originated, is the same as with the I-beam example and as with all shape pass designs, namely that for the thinnest cross section, the web, the draft stage or the relative draft is determined and from this the spread and elongation is calculated. From the principle of equal elongation the cross section of the flange in every pass is had. The maximum indirect draft at the point and at the bottom which is desired in the flanges then is calculated to arrive at the desired cross section, and this is divided between the flange and counterflange.

When the pass shape, which is assumed to be filled by the rectangular ingot, is determined it is desirable to investigate if this shape will be filled by a rectangular cross section. If that is not the case then another roughing pass should be added. The roll designer must bear in mind, that a pass design is much better, the fewer

Table X
Design of a 4.724" x 16.75 lbs. Channel

Table X Design of a 4.724" x 16.75 lbs. Channel																					
FLANGE																					
No. of Passes	Position of Pass in Relation to Flange	WEB			FLANGE			FLANGE			FLANGE										
		<i>d</i> Inches	<i>D</i> in. in. in.	<i>b</i> Width in. inches	<i>n</i> Cross- Section Sq. in.	<i>d</i> Thickness Top in. in.	<i>d</i> Bottom in. in.	<i>H</i> Center Top in. in.	<i>H</i> Bottom in. in.	<i>H</i> Total in. in.	<i>Q₃</i> Cross- Section Sq. in.	<i>n</i> Elong- ation									
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
I	Below	0.276	—	—	4.793	1.319	—	0.276	0.433	0.354	—	—	1.919	—	1.919	—	0.680	—	0.354	0.177	
II	Above	0.305	10	0.030	0.030	4.764	1.455	1.1	0.266	0.423	0.344	—	—	2.028	0.698	1.03	0.551	0.197	—	—	
III	"	0.384	20	0.079	0.039	4.724	1.814	1.25	0.325	0.541	0.433	0.059	0.118	1.988	0.059	2.047	0.887	1.27	0.709	0.236	
IV	"	0.512	25	0.128	0.049	4.675	2.390	1.32	0.374	0.689	0.532	0.049	0.148	2.087	0.079	2.165	1.155	1.30	0.984	0.276	
V	Below	0.728	30	0.217	0.079	4.596	3.388	1.4	0.413	1.004	0.709	0.039	0.315	2.106	0.157	2.264	1.621	1.40	1.181	0.354	
VI	Above	1.033	30	0.305	0.098	4.518	4.650	1.39	0.354	1.043	0.699	—	0.839	2.460	0.394	2.554	2.000	1.25	1.654	0.354	
VII	"	1.595	35	0.561	0.167	4.331	6.913	1.48	0.472	1.535	1.004	0.118	0.492	2.165	0.787	2.953	2.961	1.48	1.102	0.394	
VIII	"	2.598	Irregular			0.197	4.133	—	—	0.866	1.831	—	Irregular			1.535	0.866	2.402	—	.591	0.787
			Ingot						Ingot				Ingot			5.512 x 3.307					

the passes in which a clean and exact dimensioned final product can be obtained. If the investigation of the number of passes chosen discloses that the first pass does not fill, he should not hesitate to work over again the whole design with heavier drafts. Frequently headway can be made by deviating from the regular pass design. The method previously suggested for calculating the filling can be used in this case.

Tracing Is Recommended

Tracing and placing the passes over one another offers a necessary control and supplement of the calculation. As previously mentioned, it is impractical to draw all passes one on top of the other. This was done in the design shown in Fig. 141 to save space, and only for some passes, so that the clearness will not be lost, as to which pass the different lines belong.

The finishing pass, No. 1, is turned with the flanges in the lower roll; passes Nos. 2, 3 and 4 have the flanges in the upper; pass No. 5 again is turned; passes Nos. 6, 7 and 8 lie as passes Nos. 2, 3 and 4. The advantage of turning over the finishing pass is that the flange height can be held exactly to size. If the flanges lie above and as a mathematically exact filling never can be accomplished there originates an underfill due to low flanges, or an overfill due to flanges which are too high. The disadvantage of the turned over finishing pass is that either the flanges are wedged in easily in the finished pass or if as in Fig. 141 sufficient play is permitted, they do not become straight.

Frequently the next to the last pass is turned up, to assure the proper flange height and to avoid the recently mentioned disadvantage in the finished pass.

Columns Nos. 9 and 19 in Table X show about the same elongations except the turned-up passes, with which the flanges remain somewhat behind the web to prevent wedging-in, as mentioned with the tee pass design.

The pulling along is disregarded, as with the tee

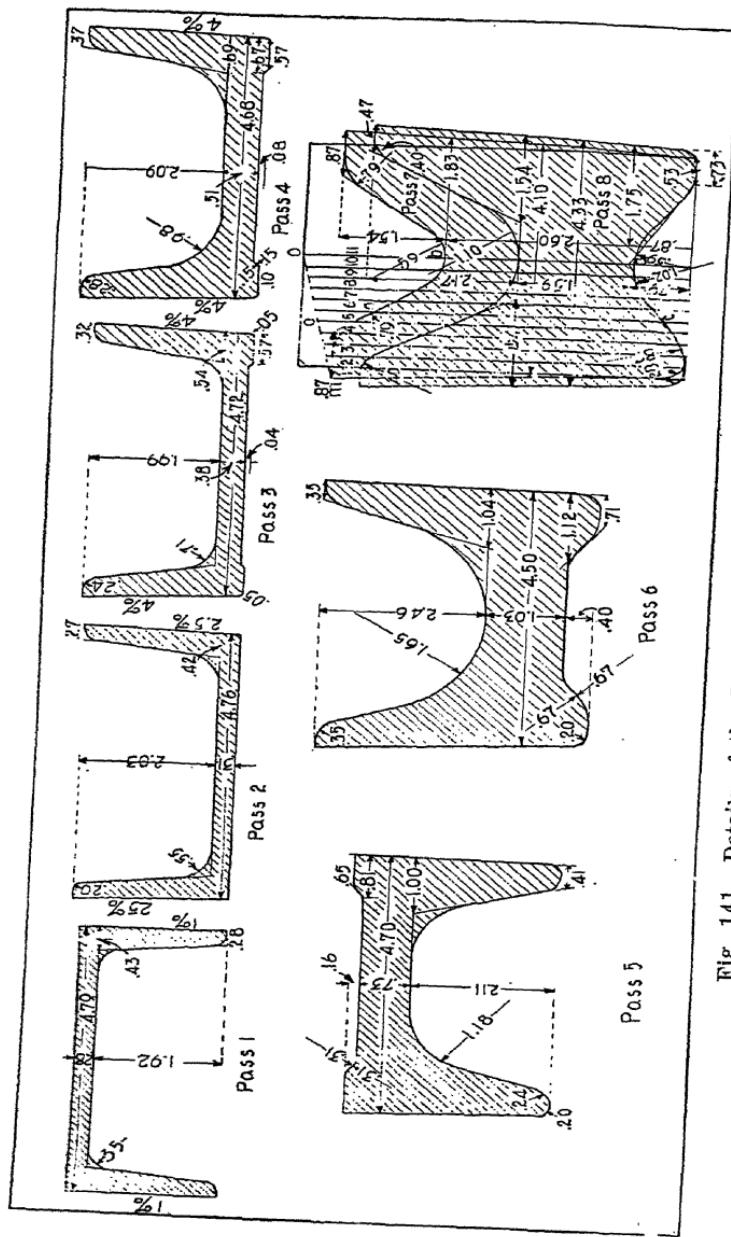


Fig. 141—Details of the Pass Design of a 4.724-Inch Channel

pass design. As previously shown it would require a greater pressure on the flanges than on the bottom. Instead, as can be seen from Table X and the design in Fig. 141, the opposite process is used to prevent the formation of the fins. The flanges have different lengths of points and bottom, which result in a holding back and shrinkage of the bottom similar to the holding back of the vertical part of the tee profiles. With sufficiently large roll diameters it is permissible. With small diameter rolls the pulling along helps by pulling away material from the outer fibers and prevents the formation of fins at the points. The difference in draft between the point and the base of the flanges can therefore be smaller.

Unequal Draft Causes Strains

The same condition applies as mentioned in regard to fillets. It is better to take the lateral pressure in the flanges too small than too large. To increase it by taking out material on a lathe is unimportant whereas a diminution can only be accomplished by turning a considerable amount from the rolls. Unequal draft causes strains in the flanges. Since the material flows easily from the more strongly pressed parts into the more slightly pressed parts of the flange and can effect an equalization the strain is less dangerous than if different parts of a profile, inclined to each other, are given different drafts. Many roll designers in considering draft pay no attention to the pulling along, or in other words, the inequality of the working diameter.

Passes Nos. 7 and 8 shown in Fig. 141 are irregular. A determination of the elongation of the individual parts of the profile from the profile into the parts would not be dependable, because the boundaries of the profile cannot be determined exactly. To ascertain the filling of pass No. 7, involves the use of the method of average elongation, and an investigation of whether an ingot or approximately the width of the pass and somewhat higher fills the first pass. Eleven ordinates are drawn on the

left side of the pass as shown in Fig. 141. Ordinates Nos. 1 to 10 are considered a second time on the right side. The ingot height is to be reduced by the line *mo*. The point, *m*, which lies in a corresponding position on the right side but different from the example as depicted by Fig. 127, also lies outside the ingot. To determine the single lengths the ingot height, H , at each point is divided by the pass height, h . At ordinate No. 11 for instance $H=5.512$ inches, $h=ab=2.717$ inches. At ordinate No. 6, $H=ce=5.276$ inches, $h=cd=4.193$ inches. H/h is in the first case 2.03, in the latter 1.26.

Ordinate	H	h	H/h
1 and 21	5.059	4.724*	1.07
2 and 20	5.118—	4.980	1.03
3 and 19	5.157—	4.961—	1.04
4 and 18	5.197—	4.843—	1.07
5 and 17	5.236—	4.567—	1.15
6 and 16	2.576—	4.193	1.26
7 and 15	5.335	4.780—	1.41
8 and 14	5.374	3.346—	1.61
9 and 13	5.433—	2.992—	1.62
10 and 12	5.472	2.953	1.97

*Ordinates 1 and 21 are smaller than ordinates 2 and 20 because of the fillet in the lower corners of the pass.

In the foregoing table for all ordinates H , h and $H \div h$ is given and the average length calculated in the foregoing manner. It is given as $(2 \times \text{the sum of all } H/h \text{ of ordinates from 1 to 10}) + (H/h \text{ of ordinate 11}) \div 21$. Therefore, $(2 \times 13.4 + 2.03) \div 21 = 1.37$. According to this the average height to which the ingot can rise after the pass is $H_m = 5.512 \div 1.37 = 4.024$ inches. On the other hand, the average pass height is $(2 \times \text{the sum of all } h \text{ from 1 to 10}) + (h_{11}) \div 21$. Therefore, $(2 \times 41.161 + 2.717) \div 21 = 4.047$ inches. The filling, therefore, is complete at about 4.047—4.024 or 0.023-inch.

The missing 0.023-inch refers to the average height of the profile. If the points of the flanges occupy only one-fifth part of the entire width, the missing part of the height, that is, the part which remains unfilled, amounts to 0.118-inch.

With profiles having flanges on both sides as the I-beam, it is only possible to work with direct draft on one

side. Therefore, if the flange is to be developed uniformly, it must be turned over after each pass. The flange side, which in one pass was bounded by one roll, must be bounded by both rolls in the next pass; that is why the 3-high mill is always the most convenient for I-beams. With this type mill the change in the draft from side to side proceeds automatically without turning the stock. If beams are to be rolled on a 2-high reversing mill, the collars can be alternated each time from positive to negative and, to avoid using too much space, one type can be placed on the left, the other on the right side of the rolls. Or two sets of rolls one with positive collars with passes Nos. 1, 3, 5, etc., the other with negative with passes Nos. 2, 4, 6, etc., can be used to carry the stock to the other roll after each pass. This arrangement is more convenient than to turn over after each pass because a lateral movement must take place anyway when changing passes.

Web of Beam Is Entered Flat

The profile of a beam merely is a double tee, the only difference is that its web cannot be entered flat and edgewise, but only flat. Its advantage over the simple tee is that the latter forces to the right and left neutralize each other, and therefore, a much heavier indirect draft in the first passes, in which the steel is still hot can be used. Furthermore, the stock flows into the two flanges easier, than in the one-sided flange of the tee. Retardation of the elongation is employed to lessen the spread and the danger of wedging-in. Moreover, the design up to the first shaping grooves remains regular as always after two passes all parts of the profile experience equal elongation. In order to save the rolls the same roughing passes generally are used for numerous finished profiles by working first with larger and then with smaller and eventually without spread. This is permissible, when the steel is hot and plastic but it is not the best practice.

In Fig. 142 is reproduced the pass design of a 4.724

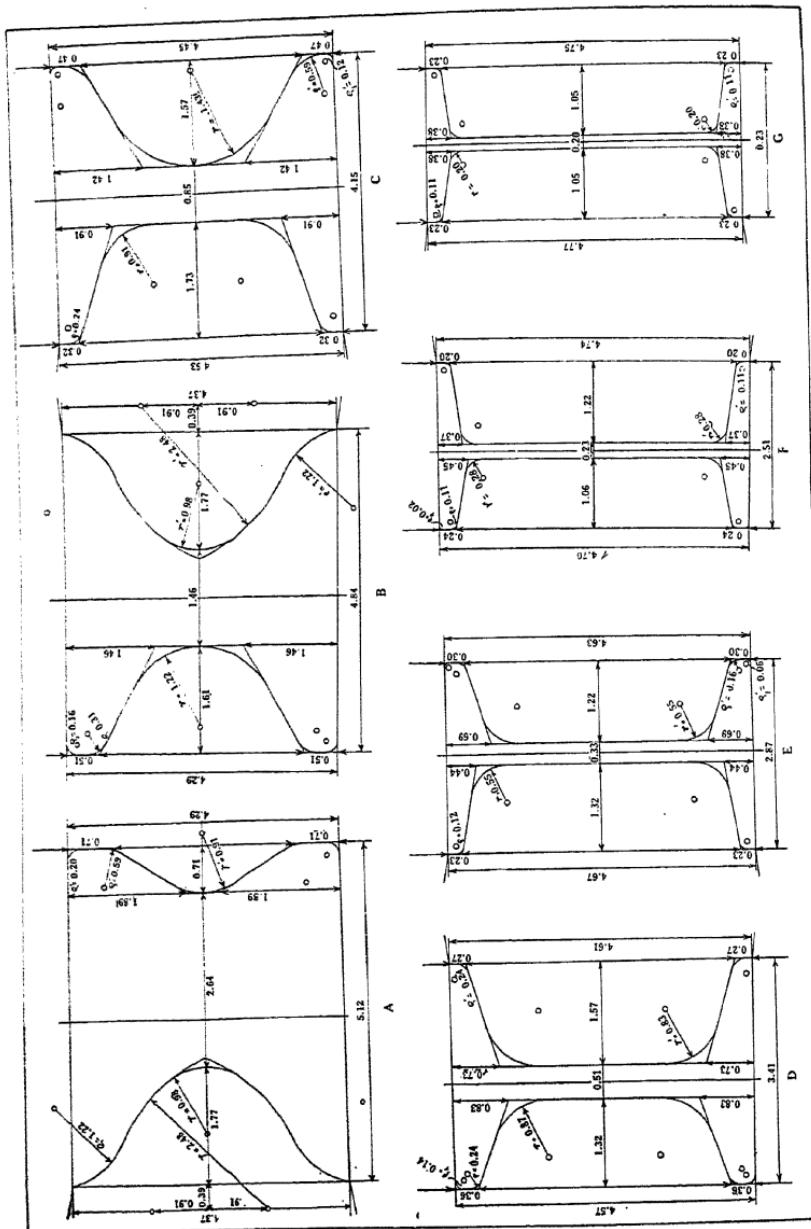


Fig. 142—Details of the Pass Design of a 4.724-Inch I-Beam

x2.283x1.673-inch I-beam. The division into single rectangular cross sections has been performed here so that the web is considered as extending the whole width which differs from the tee design. Assume the design must be placed on a single 3-high mill having a roll length of only 62.992 inches. A preliminary calculation of the number of necessary passes shows that at least

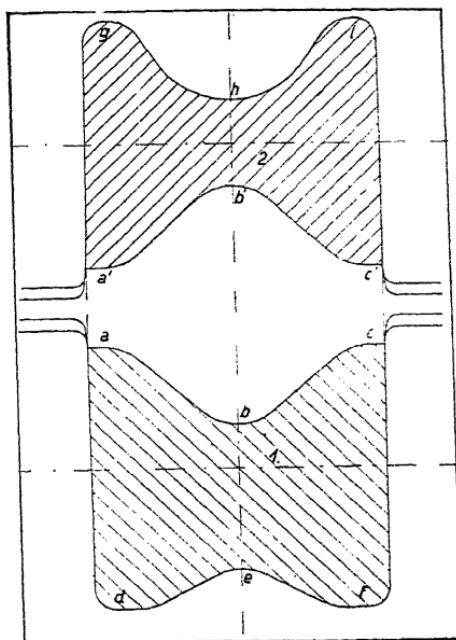


Fig. 143—Dead Pass Contour

one dead hole must be used. This presents no difficulty, if the stock is turned 180 degrees between the lower pass designated No. 1 in Fig. 143 and the upper pass designated No. 2. In that case shaping on the side of the pass designated abc , is avoided. It merely touches the outline, $a'b'c'$ in pass No. 2. As it belongs to the middle roll, it must be the same as abc . Draft and forming work between passes Nos. 1 and 2 are produced solely by dif-

ferent outlines on the other side of the pass which is designated at the top and bottom as *ghi* and *def* respectively.

Tilting Is Inconvenient

The tilting necessary in this case is inconvenient especially where good tilting devices are not available as is the case with traveling roll tables. The disadvantage is that the tilted ingot no longer lies exactly in front of the particular pass and, therefore, must first be adjusted by means of the table or the manipulator. To promote rapid and unhindered working the design must be prepared so that during the whole rolling process tilting is not necessary. This is only possible, if from pass No. 1 to 2 the flanged sides are interchanged by placing that previously lying in *abc*, on the side *ghi* and *def* in *a'b'c'*. Such a dependence of the pass design on equal pass sides such as *abc* and *a'b'c'* requires more thoroughness on the part of the roll designer, than with the simple relations assumed for the channel.

Channel Design Differs

Thirdly, the design considered in this case differs from the channel design in having larger flange drafts. If smaller indirect draft were used as with the channel, the flanges would have to receive correspondingly more direct draft to get the same elongation as the web. As the flange heights of the I-beam in the finishing pass are already higher or 2.283 inches against 2.087 inches, it would necessitate too high a starting profile or ingot. Where the part of the pass in question is surrounded by different rolls, these large indirect drafts are easily overcome. However, they lead to a more rapid wear, which has to be considered. To keep the increase in pass height low from the final pass toward the first, the following means are employed:

1. Direct draft is conserved in the pass bounded by the same roll if the elongation, compared with that of the web, is held back.
2. The direct draft in the part of the pass lying between different rolls is eliminated entirely. Since an elongation equivalent to that of the web first had to be produced on this side and then an additional amount to compensate for that which was not given enough under 1,

heavy lateral drafts result. They require large fillets. If chosen too large they are reduced easily but they cannot be increased if they are chosen too small. Fillet radii equal to the absolute indirect draft under normal conditions will suffice for the desired reserve.

The reader, who has worked out the design for the tee and the channel, will easily understand the considerations and calculations in Table XI and the pass drawings in Fig. 142.

Through the courtesy of Karl Holzweiler the design of a 29.528x11.811x0.827-inch broad flanged I-beam is shown in Fig. 144 and Table XII. This design originated through the improvement of one previously existing, in which the web inclined strongly toward buckling. This condition arises mostly with profiles having a thin web and heavy flange drafts because the web is not able to pull the profiles along, if for any reason the rolling speed is accelerated. The web moreover suffers from the excessive compressive stresses of the heavier neighboring parts and if they exceed a certain amount the web is pushed together and causes the formation of waves. The web has a much larger working diameter than is found at the tops of the flanges and between the top and the bottom of the flanges. The web is thrown forward in exactly the same manner as with a heavier draft.

Finally the wave formation often is caused by the flanges being released from the grooved roll with difficulty and thus holding back the web. To prevent the wave formation the web is drawn strongly all over and has not been given any draft in the last passes in the middle of the profile. On the contrary a gradually increasing draft against the flanges has been provided.

The web is stiffened by the slightly conical shape, which may offer an increased resistance to the formation of the waves. The strains between the flanges and web become less. The idea is to have the web pulled by the flanges instead of vice versa. If the web were to be held back over its whole length, large stresses would occur at the transition of the web to the most heavily compressed base of the flange. These are reduced with

Table XI
Roll Pass Design for a 4.724 x 2.283" I-Beam

No. of the pass	WEB				FLANGES									
	Above (Left)				Below (Right)				Above (Left)				Below (Right)	
	Draft in inches	b in inches	Q Cross- Section in sq. in.	Thickness in inches	Indirect Draft in inches	Q Cross- Section in sq. in.	Thickness in inches	Indirect Draft in inches	Outer Radius r in inches	Inner Radius r' in inches	Outer Radius r in inches	Inner Radius r' in inches	Outer Radius r in inches	Inner Radius r' in inches
I	1	2	3	4	5	6	7	8	9	10	11	12	13	14
VII	0.201	...	...	...	4.764	0.956	...	0.228	0.728	0.303	...	...	1.054	0.104
VI	0.230	12.8	0.030	0.039	4.724	1.091	1.14	0.244	0.449	0.344	0.016	0.071	1.045	0.141
V	0.329	30	0.098	0.098	4.646	1.528	1.40	0.232	0.445	0.339	...	...	1.119	0.446
IV	0.512	36	0.183	0.059	4.587	2.558	1.535	0.262	0.835	0.391	0.130	0.390	1.319	0.778
III	0.846	39.5	0.335	0.098	4.488	3.798	1.618	0.323	0.906	0.614	...	0.071	1.732	1.063
II	1.457	42	0.610	0.157	4.331	6.209	1.67	0.512	1.457	0.984	0.189	0.551	1.614	1.389
I	2.598	44	1.142	...	4.331	11.253	1.781	0.551	1.457	1.004	0.059	...	1.772	1.183
Ingot	5.118	49	2.520	...	4.134	21.158	1.98	...	...	...	...	...	...	...

*Denotes that the filling of the steel is not based on the calculation of the pass shape.
IPass shape carried out.

the proposed method, in that at the transition point the web is given a heavier draft, and due to its slight conicity the stock can flow easier from the heavily compressed flanges into the slighter elongated web. In other words, the method mitigates the abrupt draft transition between flange and web and handles the two as a whole so that, the elongation in the points of the flange starts low, then increases to the base of the flanges, in order to go again gradually to a minimum from here to the center of the web, in the last passes to zero.

Draft Is Equalized

In line 11 of Table XII the elongation of the web and in lines 19 and 27 that of both halves of the flanges, which are calculated without consideration of the pulling along, are given. In this design the web is pulled hard by the flanges. The larger working diameters of the web, however, throw it forward in comparison to the flanges and, therefore, a part of the greater draft in the flanges is equalized. If the effect of the different diameters for the points of the flanges in pass IX, are to be studied mathematically, the following should be considered.

The roll diameter is assumed to be 39.370 inches. The working diameter at the points of the flanges is 39.370—11.968 or 27.402 inches and in the web 39.370—0.827 or 38.543 inches. The relation of the two is $38.543 \div 27.402$ or 1.4. The elongation in the web equals 1.012. The draft, therefore, equals 1.2 per cent. At the flange points it must equal 1.2×1.4 or 1.68 per cent from this on, considering the pulling along. Therefore, the points of the flanges in pass IX must at least have a thickness of $(0.984 \times 100) \div (100 - 1.68)$ or 1.000 inch. In actual practice it is equal to 1.102 inches which indicates that the point of the web, compared with the web, continues to move forward for a considerable distance.

In the last passes, in which the web goes through with almost no draft, it will be smaller than in the

Table XII
Roll Pass Design for a 29.528x11.811 I-Beam

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	UPPER PLATE			WEB			LOWER PLATE			RADIUS IN INCHES		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31							
X	16	0.827	0.827	0.827	20.801	24.645	...	0.984	1.076	1.230							
IX	15	0.846	0.847	0.847	2.3	0.030	0.276	0.528	24.95	0.012	1.002	1.05	1.208	1.118	0.157	5.512	7.489	1.100	0.981	1.081	1.130	1.141	1.151	1.161	1.171	1.181	1.191	1.201	1.211	1.221	1.231	1.241					
VIII	14	0.925	0.850	0.888	4.7	0.041	0.433	0.094	25.808	0.032	1.114	1.175	1.412	0.947	41.094	5.935	8.448	1.120	1.134	1.144	1.154	1.164	1.174	1.184	1.194	1.204	1.214	1.224	1.234	1.244	1.254	1.264					
VII	13	1.024	0.906	0.963	8.0	0.077	0.551	0.543	27.511	1.066	1.119	1.191	1.613	0.185	0.244	6.280	0.277	1.121	1.193	1.819	1.506	0.469	0.414	0.398	0.398	0.398	0.398	0.398	0.398	0.398	0.398	0.398					
VI	12	1.161	0.984	1.073	10.1	0.108	0.630	0.291	27.913	1.088	1.17	2.36	1.772	0.608	0.677	6.358	11.253	1.094	1.125	1.125	1.125	1.125	1.125	1.125	1.125	1.125	1.125	1.125	1.125	1.125	1.125	1.125					
V	11	1.178	1.102	1.240	13.5	0.157	0.709	0.295	27.713	1.126	1.713	2.539	2.126	0.225	0.413	6.280	13.361	1.181	1.155	1.155	1.155	1.155	1.155	1.155	1.155	1.155	1.155	1.155	1.155	1.155	1.155	1.155					
IV	10	1.172	1.270	1.496	17.1	0.256	0.767	0.617	26.417	1.171	1.910	2.864	2.392	0.449	0.630	15.981	1.280	1.910	1.741	1.792	0.354	0.512	0.693	0.693	0.693	0.693	0.693	0.693	0.693	0.693	0.693						
III	9	2.283	1.476	1.890	20.4	0.386	0.866	0.551	48.930	1.214	2.402	3.381	2.992	0.492	0.709	6.535	19.530	1.220	2.165	1.167	0.444	0.444	0.444	0.444	0.444	0.444	0.444	0.444	0.444	0.444							
	8	1.752	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-								
	7	3.465	2.126	2.795	32.8	0.915	0.984	24.171	0.665	1.430	2.795	4.253	0.523	0.364	4.664	6.732	23.715	1.211	1.211	1.211	1.211	1.211	1.211	1.211	1.211	1.211	1.211	1.211	1.211	1.211	1.211	1.211					
	6	2.598	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-								
	5	3.189	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-								
	4	6.299	2.937	3.118	34.76	0.380	0.866	0.551	48.930	1.214	2.402	3.381	2.992	0.492	0.709	6.535	19.530	1.220	2.165	1.167	0.444	0.444	0.444	0.444	0.444	0.444	0.444	0.444	0.444	0.444							
	3	6.299	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-								
	2	9.843	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-								
	1	14.567	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-								

Figures which are crossed out denote that the Closed Pass is given in the Cloud Pass. This is permissible where the Closed Pass still has fairly oblique outlines. As in this case it is not wholly oblique, but a medium between this and Direct Draft.

Fig.

roughing passes, so that in the web the actual drafts and elongations are somewhat larger, than given by the calculation. The web is pulled and, therefore, stretched by the flanges. The wave formation, thus is hindered. The design was not laid out originally on the basis of the surface calculation, as it is here recommended for shapes and ordinarily carried out, but so that all the linear dimensions of the profiles receive the same reduction. The elongations therefore cannot agree absolutely with those theoretically correct.

The methods used in this design to lessen the abrupt transitions and to energetically prevent an acceleration of thin cross-sectional parts by small draft on the web, decreasing toward the center, deserve to be used also for smaller profiles, with which there are the dangers of large strains and wave formation.

Small Drafts Are Required

Although a half round is a simple profile, it is one of the few which necessitates deviation from the basic principle of small drafts in the finishing pass. This is permissible, because with half rounds for ornamental rods and with strap rods, etc., customers permit liberal tolerances in dimensions. With half round tires for baby buggies, it is a case of smaller profiles, similar to wire, which can be coiled in long lengths. The cooling at all places, therefore remains exactly the same. If homogeneous material is provided the main causes for unequal dimensions with heavy draft are eliminated.

Where it is a case though of large profiles with low tolerances in height and width, a finishing pass must also be provided with the half round, which has small drafts. The following considerations then do not hold for the last but for the second last pass. The draft in the former can be assumed as 5 to 10 per cent. The spread naturally is larger than with flats, because the material compressed as a rule about 10 per cent in the center prevents material at the sides going into length, so that the compressed material must give way in width.

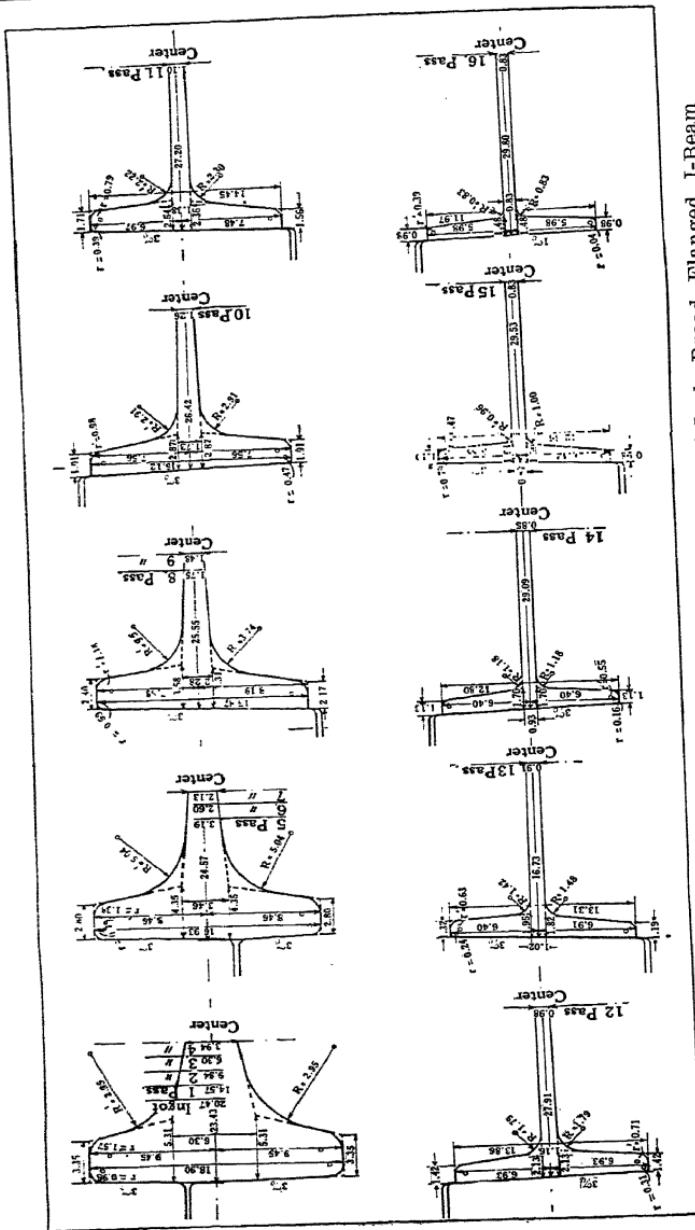


Fig. 144—Details of the Pass Design of a 29.528 x 11.61-Inch Broad Flanged I-Beam

With smaller profiles approximately the same values are received if from the rectangular roughing pass to the half round finishing pass a draft of 20 per cent of the height and an elongation of 1.4 is assumed.

This gives for a half round 0.630×0.315 -inch, a roughing pass of 0.551×0.394 -inch. As the cross section of the finished profile is $0.5 \times \frac{\pi \times 0.630^2}{4}$ is congruent to 0.156 square inch, the height of the rectangular roughing pass equals $0.315 \div 0.8$ or 0.394 -inch. From this the width $(1.4 \times 0.156) \div 0.394 = 0.551$ or for a half round 0.630×0.1575 -inch, a roughing pass of 0.472×0.197 -inch. Assuming a cross section as a parabola, the area is $2/3 \times 0.630 \times 0.1575 = 0.066$ square inch. The width of the roughing pass $(1.40 \times 0.066) \div 0.197$ is congruent to 0.472 -inch.

Ellipse Surface Gives Fuller Profile

If a fuller and more highly-arched profile is desired, which has a nicer appearance, an ellipse instead of a parabolic surface can be taken whose area is 0.8 times the rectangle of the same base and height (as against 0.66 for the parabola). The surface of the half round is then $0.8 \times 0.630 \times 0.1575$ is congruent to 0.079 square inch, the width $(1.4 \times 0.079) \div 0.197$ is congruent to 0.563 -inch. The exact adjustment of the height is accomplished by raising and lowering the roughing rolls, which are placed in a special roll stand for this purpose.

At some plants, tires for light wagons as shown in Fig. 145, are made from round edge flats instead of square edge. In shaping, a flat rod is turned up and passed through the edging roll, into which a half round depression has been cut out with a taper of about 10 per cent, as shown in Fig. 146. The spring, *s*, must be about equal to the edging draft, because the flat, due to this influence folds somewhat. For the same reason the rod, after edging, again must be passed flat through the finishing roll. The flattening is characterized by an increase

in width which has to be counteracted by a lowering of the edging roll. This is only possible, if s is large enough.

To determine the dimensions of the flat entered into the edging roll the finished profile shown in Fig. 145, is divided into three cross-sectional parts namely, *A* and *B* half-rounds, and, *C* a rectangular cross section. For the former we determine the dimensions according to the foregoing rules. The latter must receive an elongation of 1.4 as the half rounds, from which its height before the edging pass results.

If the edge parts, *A* and *B*, to be deformed were given a draft of about 20 per cent and the center part, *C*, were disregarded, a wholly insufficient rounding would result. The draft would not be transposed into the de-

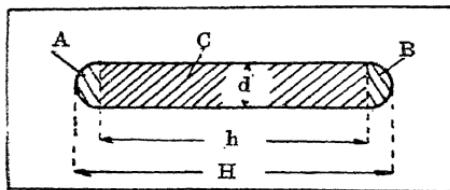


Fig. 145—Profile of a Round-Edged Tire Section

sired change in shape but would lengthen the part *C*.

For example, if h in Fig. 145 is to be 1.969 inches, d , 0.0394-inch, the final draft 0.059-inch, the spread 0.020-inch, the hot dimension to equal or approach 1.989 inches, the height leaving the edging roll, h , 1.969 inches, and the total height, H , 2.362 inches, then the roughing pass for the parts *A* and *B* or 0.394×0.197 -inch half rounds, according to the foregoing has a surface $(3.1416 \times 0.394^2 \times 1.4) \div (4 \times 2) = 0.085$ -square inch, and a height of $0.197 \div 0.8$ or 0.246-inch. The width then should be $0.085 \div 0.246$ equals or approaches 0.345-inch. The central part, *C*, also must be elongated 1.4 times and, therefore, would have a height of 1.969×1.4 or 2.756 inches. The total height of the rod to be entered into the edging pass must be $2 \times 0.246 + 2.756 = 3.248$.

inches. The thickness must be somewhat larger than 0.345-inch because the central rectangle spreads less than the half-round ends. It is adjusted by raising or lowering the roughing roll. The edging pass is given at least a width of $0.394 + 0.059$ -inch, so that it does not stick.

The beveled tire profile requires a wholly different design than the round edge tire section as the bevels

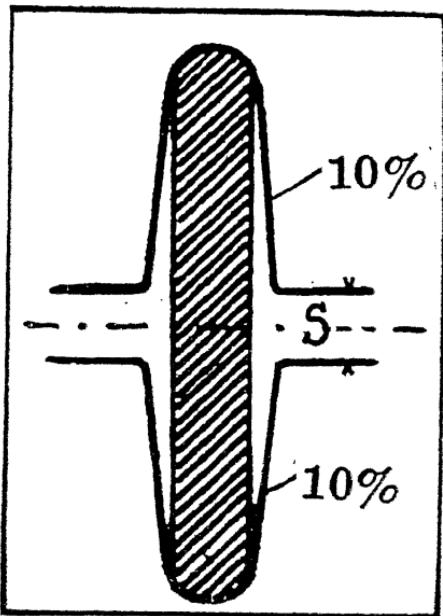


Fig. 146—Edging Pass for a Round-Edged Tire Section

shown in Fig. 147 can only be rolled flat. The development of the bevel is not possible with one draft as with the round edges for a draft of about 0.157-inch is needed to displace the material at the corners or more than is permitted in one finishing pass. A rod of about 0.394 or 0.433-inch thickness would not be sufficient as a starting profile, to roll the bevel. A draft of about 0.197-inch at the edge of the lower part of the profile would

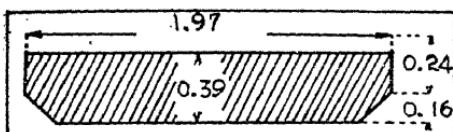


Fig. 147—Profile of a Beveled Tire Section

not squeeze away the 0.157-inch of material. Of this draft at least 60 per cent would go to the upper bevel and not to the bevel part. At the most only a 0.079-inch bevel would result. From two to three shaping passes are required depending on the size of the bevel, draft stages of about 0.079 and 0.236 and the spread as with flats from $0.25d$ to $0.35d$. The bevel is permitted to decrease from the last toward the first pass and, therefore, is chosen about 0.157, 0.138 and 0.118-inch.

Taper Prevents Fins

The parting of the passes can only be provided at the side which is not beveled. This is cumbersome, because the steel eventually will squeeze out at the particular place, forming a fin. In the starting passes it might lead to unsightly bevels and damaged material. In the finishing pass it would not be permissible. To prevent this, spread and about 5 per cent taper, is provided. The edges are not exactly perpendicular in this case but this arrangement protects the most severely stressed corners from excessive wear. Furthermore, the first shaping groove is entered with a rectangular profile so that the well rounded corners will last through the shaping passes up to the final pass. The roughing passes are made closed and the finishing passes open as shown in Fig. 148. By this arrangement any fin formation is

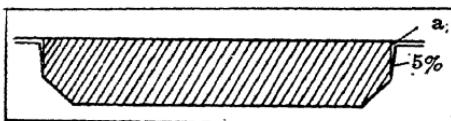


Fig. 148—Finishing Pass for a Beveled Tire Section

removed from the bearing surface of the tire. Due to the spring of the rolls the fins will occur as a slight bulb as shown at a in Fig. 148.

The principles for the treatment of periodic profiles were presented in the discussion of bar acceleration. Only such profiles can be made, with which the periodically recurring enlargement, such as a in Fig. 149, has a height which can be developed in a single draft. The position of the neutral line, HH' , is determined. If such designs for the same roll diameter and with the same overdraft are available it is best to calculate from them the relation $h_o:h_u$ as shown in Fig. 149. If this is not possible, it can be assumed as 0.35:0.65 as previously

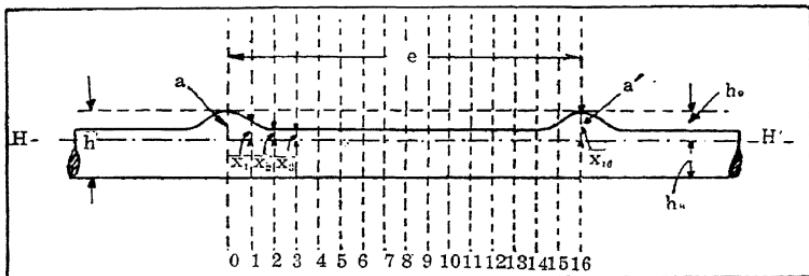


Fig. 149—Profile of the Period Type Divided into Ordinates

stated. Then the profile in one period is divided, between a and a' , into a number of ordinates of equal distance apart. This is laid off 16 times on the neutral roll circumference, HH' as shown in Fig. 150, and the radial ordinates are drawn in the roll plane. On these the ordinates, x_1 , x_2 , x_3 , etc., taken from the neutral line in Fig. 149, are entered toward the inside and the section-lined shape to be cut into the roll is obtained.

The diameters are taken as small as possible, in order to keep the spread low. The spread will be larger at the thin places, than at the enlargements, which receive little or no draft. The larger the spread, the larger will be this difference, so that with too heavy rolling the periodic rod will show visible unequal widths, which for

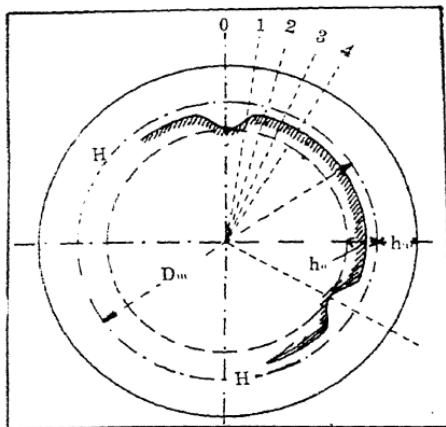


Fig. 150—Periodic Profile with Radial Ordinates in the Roll Plane

many purposes is detrimental. To be able to choose the mean diameter smaller than the mill diameter, the periodic rolls are installed at the end of the train in the finishing stands. Usually they are provided with an individual swinging drive pinion as shown in Fig. 152. The roll necks and wabblers generally are made smaller than those of the rest of the mill.

The dimensions e in Fig. 149 will be held exactly to size. The mean diameter, D_m , referred to the neutral

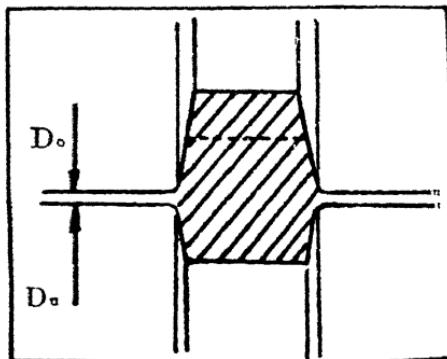


Fig. 151—Open Pass for Periodic Profiles

line, times 3.1416 must be a multiple of e . Even if this is the case with new rolls, it is no longer true with worn rolls after they have been turned. With increasing roll wear, therefore, e becomes smaller.

If the enlargement is only on one side, which is desirable, an overdraft of 0.197 to 0.394-inch can be used. The lower roll is then flat, while the upper is cut-in according to Fig. 150. For the cutting-in work, sheet steel templates are made, which span a whole period and the beginning of the next, so that an exact observance of the distance e is guaranteed.

To prevent the fin formation at the corners, mostly open passes, parted in the center as in Fig. 151 are used. The lower stripper guide then has the same form as

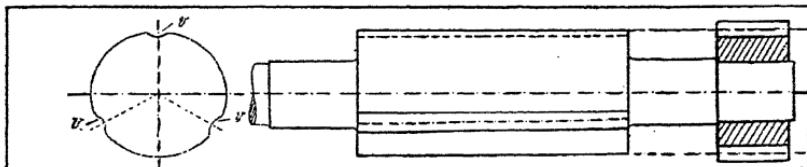


Fig. 152—Swinging Drive Pinion Suitable for Small Roll Necks and Wabblers

with flats. The upper guide, which cannot be eliminated because periodic profiles easily go around the roll, must be broader than the pass and be shaped so that it does not rest in the pass, but on the collars. In this manner, it is prevented from hitting the cut-in depressions as shown in Fig. 153. If both sides of the profile have enlargements, the last described form of guide must be used above and below.

In order to avoid the expensive and tiresome cutting-in work, flat rolls similar to the ordinary polishing or edging rolls as shown in Fig. 152 have been used for the periodic profiles. In these the depressions v in Fig. 152 are milled through the whole length of the roll body. Such rolls are cheaper to manufacture, but require good upsetting depressions and careful working, so that the

stock is not pressed square cornered during conversion.

The draft must at least be chosen so that the height h_1 of the flat rod to be entered is equal to the total height of the periodic profile as at h in Fig. 149. If the limits of the gripping of the rolls are not exceeded it is desirable to choose $h_1 = 1.05$ to $1.1 h$. Finally it is desirable to hollow out the sides slightly to avoid the fin formation at the open places of the pass and to get sharp corners on the rod to be entered. The spread is calculated as with flats from $0.35 \times (h_1 - h_2)$ for the largest draft.

The foregoing considerations are to be used for so-called ornamental iron, which is a type of periodic profile. Where much of it is rolled, a casing is often shrunk on the roll body, into which the pass is cut. When they are worn out and it is no longer possible to turn them down without too large a deviation of the distance e , the casing is replaced by a new one, while the actual roll body as well as the necks and wabblers can be used again instead of new rolls.

Profiles Classified as Complex

By complex profiles is understood the numerous unusual shapes, which are used in railway cars, agricultural machines, in the stove factory, etc. In these complex profiles can be included rails, ties, tie plates and stay plates. All the basic principles necessary to carry out such designs are given in the foregoing chapters. The foot of the rail is developed exactly as the flange of a beam or the head of a tee and each side alternately worked, first, with direct and indirect and in the next pass only with direct draft. As with the tee the web and its draft stages is the criterion for the elongation of the head and foot. The head being broader and lower than the foot, makes it easier in comparison with the design of an I-beam.

According to Fig. 30 the rail can be turned into an upsetting pass and in this manner direct draft can be exerted with the upper roll on the foot and the head. Its

development in width can be promoted considerably in this manner. At the same time such upsetting passes are used to hold the rail height and the upper edge of the head to exact dimensions. The roll designer should remember that only a light smoothing-over is possible here, because with a heavy draft on the head the thin web would buckle and the resistance, therefore, would stop. The shape of the rail, different from the I-beam, will permit placing the center line of the pass at an angle to the roll line instead of into it as shown in Fig. 154. The lower part of the foot in some cases must be bent to such an extent that both edges have a taper of at least 2 per cent. On the contrary the upper part of the foot due to its oblique position at the section-lined place can be given a much heavier, more direct draft, than could be exerted, for example, on the perpendicular flanges of

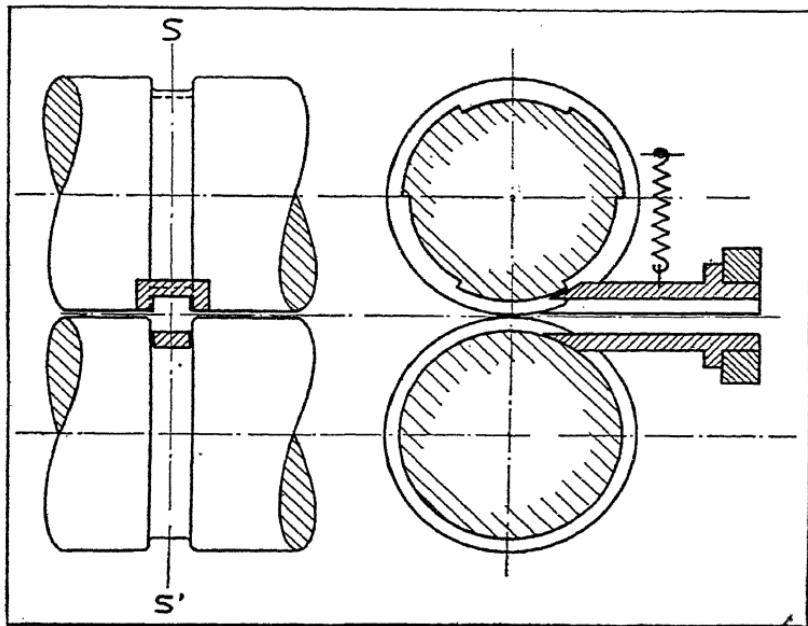


Fig. 153—Stripper Guide of a Chiseled Roll for Periodic Profiles

a channel or tee. Naturally there results from this a much larger pressure toward the side of both the upper and the lower roll. This pressure is indicated as being in the direction of the arrows as shown in Fig. 154. In order to counteract this pressure good bearing collars must be used. These must have liberal bearing surfaces and be turned for deep entering collars. No sharp corners should exist at *e*, because this would cause crumbling.

A similar attempt to convert the indirect draft of the flanges into direct, caused the development of the method of finishing H-beams with the simultaneous use of horizontal and vertical rolls shown in Fig. 155. On the whole web 1, 2 and 6, 7 direct draft is applied. The surfaces 2, 3 and 7, 8 grind and, therefore, have indirect draft. The surface 4, 5 has direct draft. The two halves of the flanges, therefore, have an average between the two. The advantages of this process, known as the Grey process, are that with the mentioned mixture between the direct and indirect draft a larger material displacement and spread is accomplished than with the latter alone. With the same thickness broader flanges can be developed. Since closed passes do not occur the danger of wedging-in disappears, and the flanges no longer need be given a taper. Their outer outlines 4, 5 and 9, 10 and

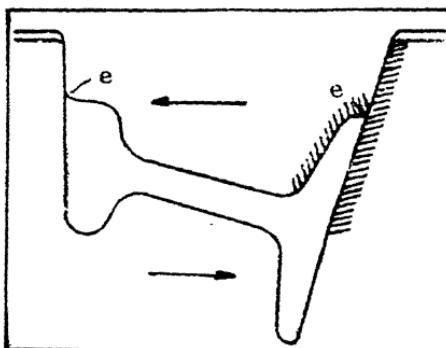


Fig. 154—Diagonal of a Rail Profile with a Taper of at Least 2 Per Cent on the Inner Side of the Lower Leg

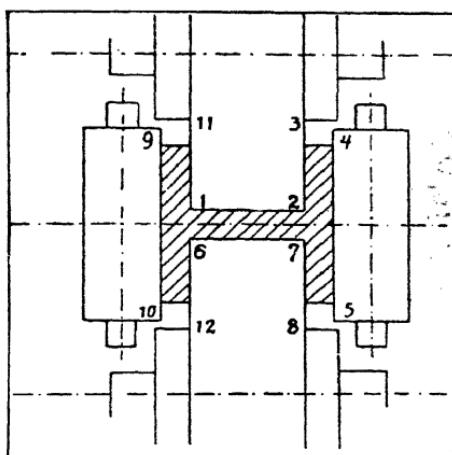


Fig. 155—Arrangement of Vertical and Horizontal Rolls for Producing Beams

their inner outlines 3, 8 and 11, 12 are therefore exactly parallel, which is an important improvement for steel construction. With the Grey mill two rolling systems placed in front of one another are combined, as shown in Fig. 155, similar to the stands of the continuous mill which are driven through gearing by the same engine. Many difficulties, which opposed the introduction of the Grey mill, can doubtless be ascribed to this common drive because the exact correspondence between exit and entrance speed of the two roll systems is never possible. The drawing is as dangerous with such heavy profiles, as a slip between the stock and the roll surface. The difficulties mentioned disappear when the two systems are driven by separate motors, which are permitted to slip, so that their speeds will adjust themselves to one another.

An additional use for the vertical rolls is the finishing of grooved rails, as shown in Fig. 156, for street railways. To press the groove into the head with the rail in a vertical position by ordinary rolls, would not do because the web is too weak to offer the necessary re-

sistance to the draft. The rail, therefore, is placed in the horizontal position and a vertical roll, which is set in a swinging bearing, presses into the head. Fig. 157 shows an outline sketch of a stand arranged for this purpose. The manner of rolling also presents some difficulties when considering that in the head a considerable material displacement or elongation takes place. The displacement can be divided with the horizontal rolls be-

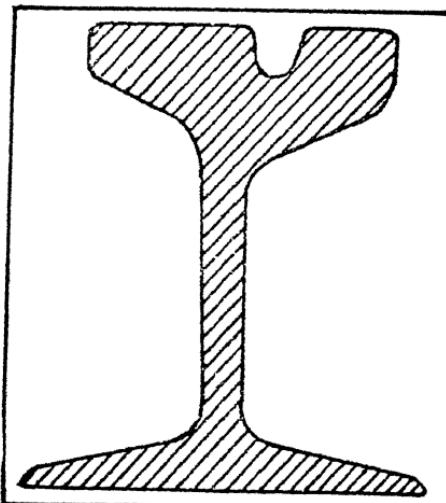


Fig. 156—Profile of a Grooved Rail Section

tween the web, and, with the indirect draft between the upper half of the foot, but in no event should the lower half receive any. That denotes in the last passes unequal draft and strains in the profile parts. An improvement is had if a second roll presses against the foot of the grooved rail, as is the case with the flanges of the Grey-type beam. The axis of this roll and the grooving roll then lie horizontal and are driven. The axes of the rolls, which hold the rail on the sides, therefore, prevent the web from kinking or folding. These rolls are vertical in the housings and are not driven. Finally the vertical rolls are used with the universal mill as shown in Fig.

158. Two or three horizontal rolls with a flat body have a pair of rolls with vertical axes installed in front or frequently in the rear. All are driven and mechanical adjustable. The axes of the horizontal and vertical rolls do not lie, as with the Grey or grooved rail mill in the same plane, but in parallel displaced planes. The object of the universal mill is, as with stepping, to be able to manufacture every possible flat profile with the same

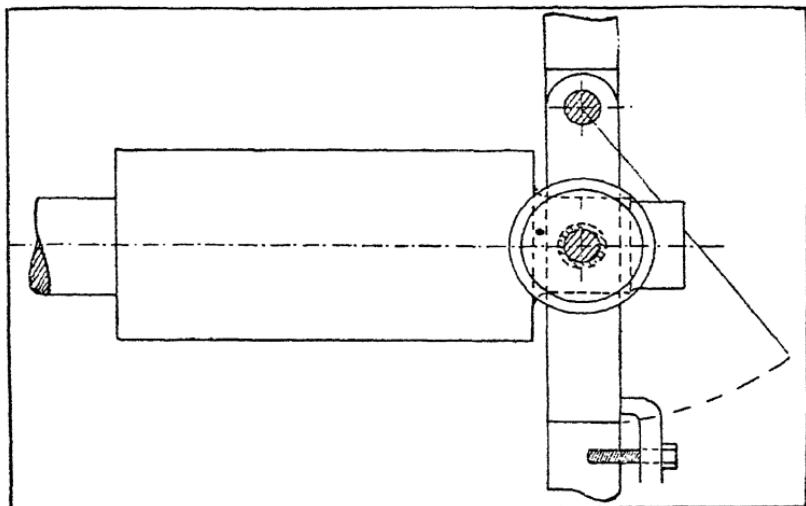


Fig. 157—Type of Swinging Roll for Grooved Rails

rolls. The range of products is not limited to narrow profiles, as is the case with the stepped rolls.

The production is considerably less, than with ordinary rod mills, because all passes from the ingot or billet must be made on the same stand, while in ordinary mills they must be completed in part simultaneously. Since the stock gradually becomes broader the body of the roll in the center is worn unevenly. The wear is greater outside in the last passes where finally the edges are used less. On the other hand, with the rolls of a rod mill the same width is always used. With rolls set ahead, a

slip either between these and the stock or in special friction arrangement set between, occurs. Finally the stands are considerably more complicated due to the vertical drives than the simple rod trains, and cause collaring. The use of the universal mill therefore is limited to commodities of which only a small amount is to be rolled and for pass rolls where first cost and cost of installation is large.

Frequently with complex profiles enlarged places

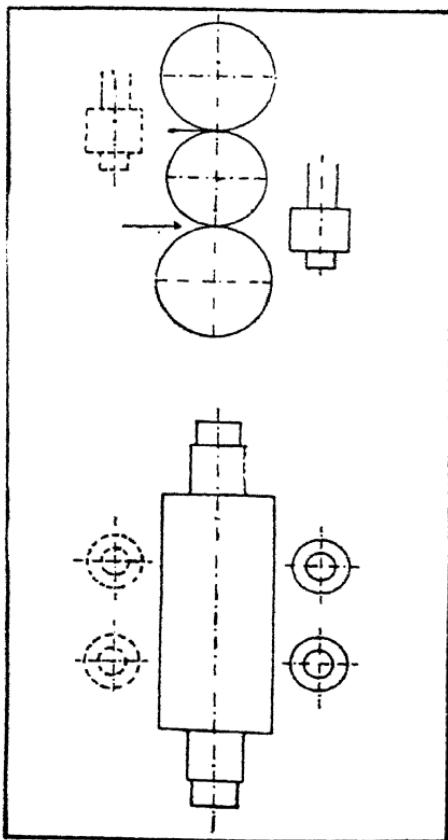


Fig. 158—Skeleton Sketch of the Roll Arrangement for a Universal Mill

occur in a section, such as with the special profile shown in Fig. 159 or with the milk-can rod shown in Fig. 35. A good plan is to develop such parts considerably in the first pass, or in other words, to transpose the major portion of the material displacement there, because the steel will flow easily due to its temperature. With such problems it is not advisable to design mechanically backward

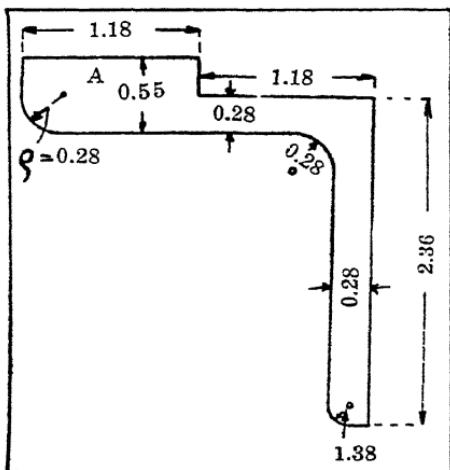


Fig. 159—Profile of a Special Section

from the finishing pass with equal drafts by means of tables. It is best to determine by sketches how to permit so much material to flow into the critical places in the first passes, so that from there on they will not receive less draft than the rest of the cross-sectional parts. In other words, preliminary considerations must precede the mathematical design. The experienced roll designer should arrange his layout so as to receive in the last shaping passes more draft in the heavy parts of the profiles than in the thin parts.

For complex profiles the rule, "equal draft for all cross-sectional parts," also applies. A deviation in the last passes is only permissible within limits of a few hundredths of the elongation and only insofar as can be

given more draft and somewhat more iron where the material will flow with difficulty. As previously mentioned, deviating from the foregoing rule, in difficult cases, frequently results in corners free from scale.

VI

POWER FOR AND METHOD OF DRIVING ROLL TRAINS

POWER required in rolling was discussed previously. The energy required for exclusively overcoming the resistance which the particles of mass offer to the respective change in their positions, without consideration of the bearing friction of the rolls and other losses in the train, was mentioned in the discussion of the Fink formula. As previously was stated, the dimensions of the draft of a blooming mill are limited by the effective capacity of the rolling mill drive. Kirchberg presented a law for displaced volumes which dealt with the product of the difference of the cross sections before and after the pass, and the length of the stock before the pass as shown in Fig. 160. In other words that part of the volume of a body to be rolled, which is taken away in height is therefore pulled into length during reduction.

This value, for want of a better one, was accepted for the investigations of Puppe on the power required for rolling. It is correct with rolling of equal elonga-

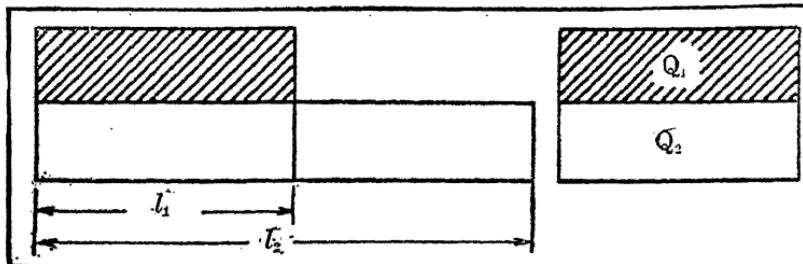


Fig. 160—Diagram for Determining Displaced Volumes in Rolling Practice

tion, but incorrect in the case of different elongations. If the stock is assumed to be stationary, the rolls pass over it similar to the wheels of a wagon, which move along on a clay surface and cut into it. The deeper the cutting-in, the greater must be the pressure exerted on the axles. In this manner the rolling pressure is dependent on the previously mentioned difference of the cross sections before and after the pass. If the roll pressure is multiplied by the path over which it is effective, the work results. As is apparent from the relative movement, this path is equal to the length after the pass.

Law Does Not Apply

If a 3.937-inch square rod 39.370 inches long is reduced 0.079-inch to a height of 3.858 inches the displaced volume is $39.370 \times 3.937 \times 0.079$ or 12.205 cubic inches. If a flat 3.937x0.118-inch and of equal length is reduced 0.079-inch, the displaced volume is the same or 12.205 cubic inches. In the first case the rod goes through the rolls with no apparent influence on the engine. In the latter case an extraordinary stressing of the mill and engine arises, which in some cases may result in a breaking of the spindles and coupling boxes. The governor will regulate for high capacity, while in the first case it will hardly react. It is, therefore, hardly possible that the law of displaced volumes is the proper rule. In the first case the rolling away of the "displaced volumes" only had about a 2 per cent elongation of the rod as a result. In the second case it was stretched to about 300 per cent of its original length.

The credit for being the first to express mathematically the theoretical power required for the elongation, belongs to C. Fink. Therefore, the formula stated by him is designated as the Fink formula. Before deriving the formula, an approximate method will be presented to make it easier to understand theoretical elongation work. From the standpoint of conservation of energy it makes no difference, if the deformation is accomplished by pressing, drawing, or rolling or in one or more stages.

Only the starting and final conditions are of consequence for the energy, which is represented by a change in shape.

A drawing process is taken as a basis for the deformation similar to that to which a test piece is subjected in the tensile machine. The rod has before the deformation a cross section Q_1 . The force required to start elongation, is called P_1 . Therefore, in Fig. 161, P_1

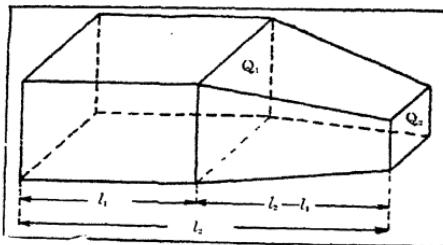


Fig. 161—Diagram for Determining the Deformation Work in Drawing

$= Q_1 k$ in which k is the elastic limit and denotes the tensile stress, with which flow sets in.

After the deformation is completed the cross section is Q_2 . At the end of the process the force P_2 , which has effected the elongation, will be $P_2 = Q_2 k'$. In hot rolling k' usually equals k , because in hot shaping no hardening occurs. Where the temperature is so low that this is the case, an average value must be used for the power required. This average value lies between the elastic limit at the beginning and at the end of deformation. For the relation of k and the temperature, see *Taschenbuch für Eisenhüttenleute* (Hutte), 1930, page 705. The length of the rod before the deformation is l_1 , and after l_2 . The average force, which is effective over the path $l_2 - l_1$, will be approximately equal to the arithmetical mean of the starting and finishing force, or approximately $[(Q_1 + Q_2) \div 2] \times k$. ($k' = k$, as previously stated.) The path, over which this force acts, is $l_2 - l_1$. The work, therefore, performed is A (theoretical) $= [(Q_1 + Q_2 \div 2)]$

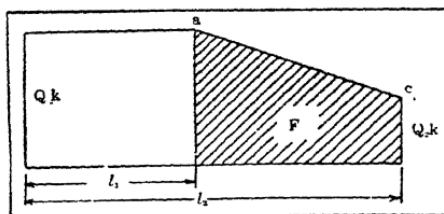


Fig. 162—Graph Which Shows Approximate Size of Deformation Work

$\times k (l_2 - l_1)$. The elastic limit, k , per square inch is approximately 14,220 pounds per square inch with the lowest rolling temperature about 900 degrees Cent. If A is desired in foot pounds Q_1 and Q_2 must be expressed in square inches, and l_2 and l_1 in feet the elastic limit is given in pounds per square inch.

The foregoing expression is approximately correct, if the relation $Q_2:Q_1=n$, that is, the elongation lies between 1 and 2 with all single passes. It becomes more inexact with numerous passes the larger n becomes.

Consideration of the foregoing derived approximate value is useful because it develops the work without the use of higher mathematics. Second, because the expression in question does not include natural logarithms. Third, because it gives the necessary clearness as relating to the value, in which each factor is to be entered into the exactly derived formula. For large elongations, it must be remembered that the assumption, the average

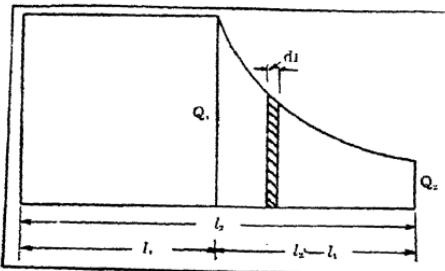


Fig. 163—Diagram for the Derivation of Deformation Work

force $P_m = (Q_1 + Q_2) \div 2$, is only hypothetical. That this is not exactly the case is shown graphically. In Fig. 162 the product $[(Q_1 \div Q_2) \div 2] \times (l_2 - l_1)$ represents the area of the dotted line trapezoid. In the foregoing equation $Q_1 - Q_2$ are considered as ordinates and not planes:

With our assumption, therefore, the increase in length proceeds according to a straight line. This is not the case. Rather the process has to follow a hyperbola, because the volume, that is, the product $Q \times l$, remains constant. The line, dc , according to Fig. 164 is not straight, but hyperbolic. The approach of the formula first developed to the exact value is so much larger, the

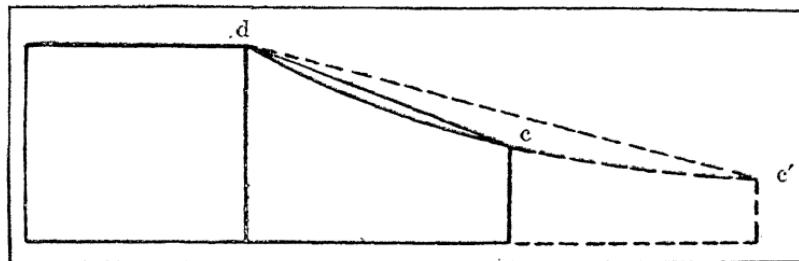


Fig. 164—Diagram for Deformation Work as a Hyperbolic Function

smaller the elongation $(l_2 - l_1)$, that dc fits the hyperbola better than dc' .

For the exact determination of the theoretical deformation work the increment of the work, dA , is considered (small hatched area in Fig. 163) $dA = k \times Q \times dl$. The quantity, $k \times Q$, is the force at any point which effects the deformation, while dl represents the infinitesimal distance which is covered by such a deformation. If the differential, dl , is taken with respect to l , the foregoing equation becomes $da = k \times Q \times l \times (dl \div l)$. The entire work over the path, $l_2 - l_1$, therefore, is $A =$ the integral between l_2 and l_1 of $k \times Q \times l \times (dl \div l)$. In this equation k is assumed constant and $Q \times l$ (=the volume) is constant so that $A = k \times Q \times l \times$ the integral between l_2

and l_1 of $dl \div l$. This equals $k \times Q \times l \times l_n (l_2 \div l_1) = k \times Q \times l \times l_n = k \times V \times l_n$ foot pounds.

As with the approximate derivation, Q is substituted in square inches, l in feet, if k denotes the elastic limit in pounds per square inch and A results in foot pounds. Therefore, V must be substituted in cubic inches $\div 12$. The value, V , would have to be divided by 12 as the path is contained in it and is expressed in inches instead of in feet and, therefore, is 12 times too large. The practical value of the foregoing formula is shown in the following example.

Calculating Power Requirements

In determining the power required to roll an ingot 7.874 inches square and 3.281 feet long into a billet 1.969 inches square, the elongation $n = Q_1 \div Q_2 = 62 \div 3.877 = 16$. The volume, V in cubic inches, is $7.874 \times 7.874 \times 3.281 \times 12 = 2441$ cubic inches. The natural logarithm of 16 is 2.8. Therefore, $A = 14,220 \times (2441 \div 12) \times \ln = 8,101,000$ foot pounds. If 30 ingots of this size were to be rolled on a mill in an hour, a capacity $L = (30 \times 8,101,000) \div (60 \times 60 \times 550)$ or 125 horsepower theoretically would be required. If the actual power requirement is desired, the efficiency of the process must be known. According to the evaluation of a number of experiments by Puppe it ranges between 50 and 60 per cent.

Using the minimum figure, L effective, therefore, is $2 \times 125 = 250$ horsepower for the rolling process. When the mill is running light approximately 150 horsepower is used thus making the total power requirement 400 horsepower. This figure may be taken as a basis for the calculation of the coal required. This value, however, is too small for the determination of the engine size because of the rolling pauses. Assuming the pauses amount to $66 \frac{2}{3}$ per cent of the total time, the capacity of the engine would be $L_m = 3 \times 250 = 750$ plus 150 horsepower consumed in running light or a total of 900 horsepower.

The relation of the rolling pauses to the total work-

ing time can be determined either by a stop watch on similar trains or mathematically. In the latter event the production per hour, if the train were to operate without interruption, should be determined and this compared with the actual production. The latter number subtracted from and divided by the former, is the relation sought.

Spread Always Present

The foregoing derivations were based on the fact that all deformation work is effective in the longitudinal direction and, therefore, transposes itself into elonga-

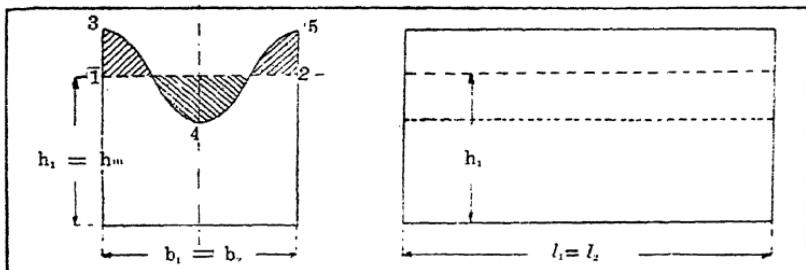


Fig. 165—Diagram Showing Deformation Work Without Elongation or Spread

tion. Actually there always will be spread in addition. Theoretically in the working of a rod, deformation can take place if the length and width remain the same. The outline in height though has changed. As shown in Fig. 165 the straight outline 1, 2 has become the curve line 3, 4, 5 in which $b_1 = b_2$ and $l_1 = l_2$, $Q_1 = Q_2$.

The following formula derived by Preussler applies for a rod whose displaced material goes into length and width: $A = k \times V \times \ln(h_1 \div h_2)$ in which h_1 is the height before and h_2 the height after the pass. For a rod, which has shaping similar to that shown in Fig. 165, in addition to the elongation and spread, the following formula applies: $A = k \times V \times \ln[(l_2 \times b_2 \times V_{u2}) \div (l_1 \times b_1 \times V_{u1})]$, where V_{u1} denotes the rectangular prism surrounding the body

at the start and V_{u_2} at the end, l_1 and b_1 are length and width before, l_2 and b_2 length and width after the pass.

The correctness of the first foregoing formula, compared with the Fink formula and that of the displaced volumes which neglect the spreading work, is illustrated by showing that the formula by Fink and the formula of displaced volumes give the same work for an ingot 7.874x7.874x39.370 inches if rolled to a slab 7.784x0.492-inch or to a sheet 62.992x0.062-inch, while the relation $k \times V \times \ln(h_1 \div h_2)$ is 5,772,000 foot pounds in the first case; in the latter case it is 10,112,000 foot pounds or almost double. For the second case considerably more power must be used. Unfortunately the foregoing improved expression for the roll work can be used only for a single pass, or for several and only then if the stock never is turned 90 degrees. Where these premises do not hold edging passes are put between them and under their influence the effect of the spreading work in the previous passes disappears. The elongation, therefore, is included in the calculation and the spread added to the losses, which are expressed in the efficiency. Only where the final product is broader, or shows a larger circumscribing volume as the final product, should the foregoing equations of Preussler be used.

In *Stahl und Eisen* 1919, the author determined the efficiency for various profiles from the Puppe tests and found values from 25 to 60 per cent. It lies higher for the rectangular cross sections, with which the actual and circumscribed profile is identical and it lies lower for shapes, with which both are different thereby confirming the Preuss considerations.

The efficiency falls further with the number of roll necks in the mill, because the roll neck friction makes up the major part of the losses, as Hammerschmidt and Babin* among others, have determined. Because of the time the mills are unoccupied when rolling small profiles, in relation to the actual work, the efficiency natur-

**Stahl und Eisen*, Vol. 52 (1928) page 1824.

ally must be low, as with wire mills. It is sufficient for power calculations to use round figures and assume about 50 per cent efficiency for square and roughing passes, 33 1/3 per cent for rod and shaping passes and 10 per cent for wire mills.

Further Accuracy Unnecessary

There is no necessity to carry the refinement in these values any further in practice, because considerable fluctuations in rolling temperature and in compressive strength must be dealt with. Temperature measurements do not offer any remedy, because they give only the values at the surface of the ingot, and not the average temperature on the interior, which is all important.

In using the foregoing values for the efficiency (η) the effective rolling work is $A_{\text{eff}} = KV \frac{1}{\eta} l_n n$ in which K is set equal to 14,200 pounds per square inch. This value can be substituted without considering the rolling temperature because it also was used as the basis for determining the efficiency from the Puppe tests. The only assumption is that the rolling process, for which the power requirement is to be determined, takes place at approximately the same temperature, as was used in the Puppe tests, namely at the usual rolling temperature.

This method, which is only approximate has been attacked in the literature and it was demanded that another temperature be used as the basis for the calculation, namely that of Puppe and which was measured during the rolling process for which the power requirement is to be determined. This undoubtedly would give more accurate results, provided, that it would be possible to measure the actual rolling temperature of the stock. Since only the surface temperature can be measured (probably done with the Puppe tests) nothing remains but to accept it for simplicity, because the temperature and also the compressive strength in hot rolling always varies within the same limits. This assumption is im-

material, if $K=14,200$ pounds per square inch or to another value, provided the same value is used for the determination and application of the efficiency. In other words the value K is cancelled by the calculation of the power requirement. In the evaluation of the Puppe tests instead of setting it equal to 10, it could have been set equal to x . The efficiency η then would have been changed correspondingly, but the effective work calculated therefrom would have remained the same. Exception then perhaps would not have been made. The value

$\frac{x}{\eta}$ calculated in place of the efficiency η would not have

been a value that could be represented*. To make this possible, in place of the variable x for the compression strength, the value 14,200 was included in the calculation.

Assumption Effects Cancellation

That K actually is cancelled, if it is assumed of the same size in the calculation and application of the efficiency, is shown by the following calculation: The work A_g measured by Puppe must be equal to the theoretical $(V K 1_n n)$ divided by the efficiency (η) . Therefore $A_g = (1 \div \eta) \times KV1_n n$. Therefore, $\eta = (KV1_n n) \div A_g$. Assuming that for the value K of compressive strength any other value is used, for example $z \times K$, then from $\eta^1 = (zKV1_n n) \div A_g$, the value for η^1 is $z \times \eta$. This relation shows the higher the compressive strength is assumed, the higher must be the efficiency with the same effective work and vice versa.

Applied to another case, a compressive strength equal to $z \times K$ must be substituted for K as well as a substitution for the newly calculated efficiency $\eta^1 = z\eta$. In this case

*For more detailed discussion see *Zeitschrift fur Metallkunde* (1924) pages 391 and 430.

$$\begin{aligned}
 A_{eff} &= \frac{1}{\eta^1} V z K l_n n \\
 &= \frac{1}{z\eta} V z K l_n n, \text{ therefore} \\
 &= \frac{1}{\eta} V K l_n n, \text{ as above}
 \end{aligned}$$

The driving of rolling mills, which was previously considered for blooming mills, can be done:

1. Directly by hydraulic motors, water wheels and turbines. The water wheel drive was the only means available before the invention of the steam engine; it was still used as late as the middle of the 19th century, but has been displaced in the more recent rolling mills by the turbine. The reason is, that the water wheels were not suitable for large capacities. Inclusive of the inlet and outlet of the water they were more expensive per horsepower-hour than turbines, and they have a low revolutions per minute, making necessary a conversion to high speed. This is undesirable where large impacts occur in gearing transmissions as is the case with rolling mills. The drive of the roll motors by water turbines is seldom used, but is successful, where the regulation as to output and revolutions per minute is sufficient.
2. Direct drive by steam engine.
3. Direct drive by internal combustion engines.
4. Indirect, electric drive. The electrical energy is produced in primary generators driven by water or steam turbines, or steam or gas engines in the power house. This energy is converted into mechanical energy in the "secondary" rolling mill motor.

Many objections are taken to the direct drive by internal combustion engines listed under item 3. Their thermal efficiency with equal load however, is more than twice as high as with the steam engine with an inlet pressure of 15 to 20 atmospheres, which is the usual practice in steel mills. The heat used for horsepower-hour in the reciprocating steam engine compared with that used in the gas or diesel engine, in as far as they enter into the question of rolling mill engines, is about 3:1 to 5:1 with normal output. In case the load is low for a large part of the time, the efficiency falls with gas engines, much more than it does with steam engines, particularly reciprocating steam engines. According to the investigations of H. Hoff* the use of calories in the

**Stahl und Eisen* (1912) page 784.

4-cycle blast furnace gas engine at normal, three-quarter and half load varies as 1:1.38:2.05 while with the same values for a reciprocating steam engines vary as 1:1.04:1.15.**

The heat used in the reciprocating steam engine approaches that of the gas engine, if the operation of the rolling mill engine averages 50 per cent of the normal output; and exceeds it if the average load, as is frequently the case, is below 50 per cent. The reason for the low sensitivity of the steam engine to overload is that the heat used principally depends on the degree of expansion, and therefore on the final pressure of the steam. With decreasing load and cut-off of the steam engine, the degree of expansion rises, and the final pressure decreases. This explains why the condensation or radiation losses and mechanical losses, which increase proportionately with combustion and steam engines, for the most part are equalized by the low final pressure.

Excess Capacity Is Essential

The rolling mill engine must be chosen considerably larger, than required by the mill. In reversing mills, which do not have a flywheel, to permit rapid stopping and reversing, the driving engine must be able to develop the maximum power requirement (see Blooming Mills). In mills with flywheels the engine can be chosen somewhat smaller, because the flywheel takes care of the momentary peaks, which occur, for example, if rolling is taking place simultaneously in all stands, or if a cold piece is passed through the rolls. The capacity of the engine, however, must be higher than the average power requirement of the mill, because the flywheel cannot take care of peak loads which occur in the rolling of heavy sections or hard material. The engine capacity based on such unfavorable cases, will be about 100 per cent larger than the average power requirement of the mill. Exceptions are wire and other high-speed mills,

***Stahl und Eisen* (1913) page 1895.

which have a uniform power requirement, and with which a capacity 30 to 50 per cent larger than the average will be sufficient.

Where the loads are considerably below capacity, the diesel engine is more favorable than the gas engine. The heat used increases but little with loads below 50 per cent capacity. The diesel unit can be controlled and reversed easily, as is proven by its application to the driving of ships. The disadvantage is that it requires liquid fuel, while in the rolling mill as a rule only gaseous or solid fuel is available. For this reason its use as a rolling mill drive has been prevented.

Advantage of Reciprocating Unit

The fact, that the efficiency of the reciprocating steam engine decreases but little down to 50 per cent of capacity, has the advantage that the size of the rolling mill engine can be chosen larger than is necessary when the mill is installed. This will afford considerable power reserve for future needs in event conditions warrant an increase in the number of roll stands, production or the speed of the mill. This is not the case, however, with the gas engine.

Furthermore, the reciprocating steam engine easily is regulated according to revolutions per minute and output: the simple expansion engine is better than the multiple expansion unit in that it permits heavy overloads above normal capacity. In fact, in this case the efficiency drops considerably because the steam pressure rises; the high steam pressures exhaust large quantities of heat into the air or into the condenser. If such impact type overloads seldom occur, they have little influence on the average heat consumption. Then, too, the engine will pull under heavy overload whereas the gas engine would stall. With good attendance, particularly lubrication, a steam engine will run without repairs for years or decades, other than renewal of the stuffing-box packing, tightening and occasional replacement of pis-

ton rings and the regrinding of the slides and valves. The latter is best done at regular intervals to minimize the leakage losses.

Finally for mills, with impact-type power requirements (blooming and large shape rolling mills) not served by large power plants, the steam plant has the advantage that the superheated water in the boiler provides an energy storage. If large quantities of steam suddenly are taken from the boiler, during the first passes of a blooming mill, the steam pressure and the temperature in the boiler decreases. All energy stored in the highly heated water, instantaneously is converted into steam heat. This occurs with pronounced ebullition in the boiler, which also promotes the development of steam. How considerable the reserve is, which is made available momentarily in this way, can be derived from the following consideration. A medium sized boiler of 700 cubic feet water space, in which a sudden demand of steam reduces the pressure from 16 to 6 atmospheres (absolute) and the temperature from 200 to 158 degrees Cent. immediately makes available, 20,000 cubic feet of steam at 6 atmospheres. This effect of the boiler as a storage place for energy can be increased artificially by an exceptionally large water space or by a Ruth steam storage or Kilselbach feed-water storage.

Gas Holders Afford Reserve

With the gas engine a similar reserve is only possible by the installation of large and expensive gas holders; with electric motors no reserve is possible, because storage batteries of the sizes which would be necessary for heavy rolling mills are too expensive.

All of the previously mentioned properties of the combustion and steam engine have brought about the condition that the latter type has displaced the former in wire mills, insofar as it is a question of the direct drive of rolling mills. At the present time the competition is more between the direct drive by means of the steam engine (to the reciprocating engine has recently

been added in isolated cases the steam turbine with precision gearing) and the electric drive.

While at the present writing the opinions of both methods still differ considerable, the electric drive is preferred practically without exception. Where the direct steam drive still enters into consideration at the present time, the steam lines from the boilers to the rolling mill engine are short, whereas those to the power plant would be long, as is the case with exhaust heat boilers behind pusher furnaces in rolling mills. With the self-contained power plant where the steam boiler is at the rear, the rolling mill engine in front of the pusher furnace will give a much better gross efficiency (it must be investigated mathematically from case to case), than if the steam were sent to the central station to produce electric current and then lead back from there to the rolling mill. As the steam production does not always meet the steam demand it is assumed that a spare boiler with grate or powdered-coal firing is provided, which is located next to the exhaust heat boiler or combined with it.

Details of Ilgner System

Another case, for which at the present time the steam installation still is considered, is small central stations and blooming or large shape mills whose current impact can influence the voltage in the line. In fact, it is possible to protect the mills from current impacts by the Ilgner transformer. The latter consists of a shaft on which is mounted an electric motor of about average mill output including the losses to this point fed from the line. On the same shaft is located a rapidly running flywheel and behind this a so-called regulating dynamo, which produces the current for the rolling mill motor. By means of the Leonard circuit the motor can be reversed in the direction of turning and varied in speed from zero up to maximum. If the mill requires more energy than corresponds to the capacity of the electric motor fed by the line, the speed decreases as

does that of the flywheel, which with the reduction of its speed gives up energy to the shaft. In the regulator dynamo the uniform capacity of the power line is added to the energy given up by the flywheel. The Ilgner transformer at the same time cuts off the flywheel of the rolling mill toward the transformer shaft. The machines, regulating dynamo and rolling mill motor, lying behind the flywheel must be of such size as to satisfy the maximum demands of the mill, because this no longer possesses a flywheel. They are used only at the maximum load, and with average operation they run with considerable underload.

Controls Speed of the Mill

The Ilgner transformer is the most elaborate arrangement for reversing and controlling the revolutions of a rolling mill. It has the disadvantage, however, that the three electrical machines between the power line and the rolling mill and the underloading, with which two of these run, occasions losses up to 40 per cent. It, therefore, is not efficient for the average mill and for reversing mills if these can be used to full capacity. Where this is not possible as is often the case in small mills, the direct steam drive often will be more economical, than the electric with the Ilgner transformer.

If reasons for the use of electric drives are questioned in spite of the losses in the primary and secondary machines and in the lines in all other cases than those previously mentioned, it should be borne in mind that industry has learned to build electric motors so that they are less sensitive to overload than previously, and that they approach the steam engine in this relation. The advantage of the steam engine, therefore, has become less in one important point.

In addition the horsepower-hour in large power stations with internal combustion engines or steam turbines of large capacity or combined installation of back-pressure piston engines and low-pressure turbines, is considerably cheaper than can be produced in individual

rolling mill engines. The heat used in such modern steam plants of 30 to 50 atmospheres is not more than that of a single large gas engine. To exceed such pressures is not recommended in steel plants.

The cheapening of the horsepower-hour in large power plants in comparison with individual driven engines is more than sufficient to equalize the loss in transforming the mechanical energy into electrical and back into mechanical. In round figures these losses amount to about 7 per cent in every electrical machine and approximately 5 per cent in the lines, while the cost of the horsepower-hour in an individual rolling mill motor in comparison with that in a large power plant may be two or more times as large. The losses in electric lines are smaller than the heat losses in steam lines even with well insulated steam lines (an important requirement of every good steam plant) and stop altogether when the rolling mill is idle, while the radiation losses of steam lines continue regardless.

Electric Units Occupy Less Space

Repairs required by the electric machines are still less than for piston steam engines. The former take less space than the latter, which is of importance with the small amount of space available in the rolling mill. With heavy varying loads the small amount of space required generally permits separating the regulating dynamo of the Ilgner transformer into units. If the power requirements of the mill falls to 50 per cent or less, one of the two machines can be run light and the other can be driven with full or approximately full load, therefore, with good efficiency.

Finally, the electrical transmission permits the production of energy by large gas engines, if by sufficient subdivision of the machines and by peak machines (steam turbines or diesel motors) provision is made that the loading of the gas engine is uniform to a certain extent.

The advantage, afforded by the use of gas engines

in the central station for the energy production, or steam turbines of high thermal efficiency with gas-fired boilers, is of considerable importance for the rolling mill, because the use of blast furnace gas, where such is available in a steel plant, for the production of the energy required is a principal requirement of a good heat efficiency.

It is also of some influence, that the current used can be measured more easily and dependably than is the case with steam. Further the costs of attendance and for oil used are smaller with the electric motor, than with any other power machine. Finally there are cases, in which the power plant is already available. Then the electric motor as a rolling mill driving engine is cheaper than the reciprocating engine.

Factors Which Simplify Operation

The electric drive is so convenient, so easy to regulate for capacity and speed and to reverse and control automatically by electric current and voltage instruments, that at present the endeavor is to apply it, where the efficiency of the primary and secondary plant taken together is somewhat lower than that given by the direct drive with the steam engine. There are exceptions, as previously mentioned, where in the design of new rolling mills one cannot avoid considering the use of the direct steam drive even today. The values for the steam or electric consumption guaranteed by manufacturers, and the interest and amortization of the installation costs in combination with the waiting costs and the probable repair costs prompt a decision, as to which of the two installations is more efficient for the particular local conditions. Calculations, therefore, should be made with the average load, for the maximum and finally for the minimum.

How these loads can be calculated from the theoretical deformation work and the efficiency of the rolling mills for the different profiles and hourly production was presented in the chapter on power requirement.

The times, which are to be set in for the different loads, must be estimated according to the rolling program, which is planned for the particular mill.

The choice of drive can be made only on a basis of calculations as have been designated. Only when the basis for such calculations are too indefinite and uncertain, would they be chosen roughly. For wire and rod mills the electric drive generally is suitable and for shaping and blooming mills also if they are to be used at full capacity. Where the latter two are not used to capacity, a direct-steam drive will meet requirements.

The object of this book has been to show in individual cases that roll pass design and layout of the mill and its drive are problems which can not be handled separately. Moreover, the considerations and calculations for all three must go hand in hand. The engineer, therefore, cannot proceed without the co-operation of the mill man. The fact, that many rolling mills have originated otherwise, in that they are simply purchased complete from the manufacturer, later provided with the drive and finally with rolls by the roll designer, does not contradict this statement. Few rolling mills, which in relation to fitting the rolling program and all other local conditions, are entirely free of criticism.

If this book is successful in contributing data to improving this condition, it has fulfilled the purpose for which it was written.

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